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State of California
AIR RESOURCES BOARD

CAPCOA/ARB PROPOSED DETERMINATION OF REASONABLY AVAILABLE CONTROL TECHNOLOGY AND BEST AVAILABLE RETROFIT CONTROL TECHNOLOGY FOR STATIONARY INTERNAL COMBUSTION ENGINES

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PROPOSED RACT/BARCT DETERMINATION FOR STATIONARY INTERNAL COMBUSTION ENGINES

I. INTRODUCTION

This report presents the proposed determination of reasonably available control technology (RACT) and best available retrofit control technology (BARCT) for stationary reciprocating internal combustion (IC) engines. This report also presents the basis for the proposed determination, an overview of the control technology, an assessment of the cost and cost-effectiveness, and the expected associated economic and other impacts.

The State Health and Safety Code Section 40918(a)(2) requires nonattainment areas that are classified as moderate for the State ozone standard to include in their attainment plan the use of RACT for all existing stationary sources, and BARCT for existing stationary sources permitted to emit 5 tons or more per day or 250 tons or more per year. This requirement applies to the extent necessary to achieve standards by the earliest practicable date.

The State Health and Safety Code Section 40919(a)(3) requires nonattainment areas that are classified as serious for the State ozone standard to include in their attainment plan the use of BARCT on all permitted stationary sources to the extent necessary to achieve standards by the earliest practicable date.

In developing this determination, the Air Resources Board (ARB) staff reviewed a number of reports on IC engines, vendor literature, source test data, district rules and accompanying staff reports, and other sources of information. The determination was developed with the assistance of, and in coordination with, several representatives of California's air pollution control and air quality management districts (districts), working within the framework of the California Air Pollution Control Officers Association (CAPCOA). The districts have responsibility under State statute for control of air pollution from stationary sources. The districts are also responsible for developing plans to achieve healthful air. These plans include strategies such as adoption of specific emission-limiting regulations.

Stationary IC engines are major contributors of NOx emissions to the atmosphere. The 1994 point source emissions inventory for stationary sources includes 89 tons of NOx per day from IC engines. This inventory is based on data from district permit files. Table 1 summarizes this inventory by district.

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Table 1

NOx Emissions Comparison Between
Permitted Stationary IC Engines and All Stationary Sources
(Source: 1994 ARB Point Source Inventory)

District*	NOx in Tons Per Year		
	IC Engines	All Stationary Sources	Percent of Total
Amador County APCD	3	900	0.3
Bay Area AQMD	1,750	40,000	4.4
Butte County APCD	14	580	2.4
Colusa County APCD	710	1,500	47.3
Feather River AQMD	359	1,200	29.9
Glenn County APCD	28	910	3.1
Great Basin Unified APCD	31	250	12.4
Imperial County APCD	1,225	3,500	35.0
Kern County APCD	5	5,500	0.1
Mojave Desert AQMD	7,600	28,000	27.1
Monterey Bay Unified APCD	145	13,000	1.1
Northern Sierra AQMD	48	500	9.6
Placer County APCD	3	440	0.7
Sacramento Metropolitan AQMD	74	1,600	4.6
San Diego County APCD	790	5,800	13.6
San Joaquin Valley Unified APCD	7,155	58,000	12.3
San Luis Obispo County APCD	245	1,900	12.9
Santa Barbara County APCD	1,273	1,900	67.0
South Coast AQMD			
Southeast Desert Air Basin	1,863	6,300	29.6
South Coast Air Basin	8,534	17,000	50.2
Ventura County APCD	527	3,500	15.1
Yolo-Solano AQMD	33	1,200	2.8
Totals	32,415	193,480	16.8

* APCD = Air Pollution Control District
AQMD = Air Quality Management District

ARB/SSD December 3, 1997

As can be seen from Table 1, IC engines are responsible for a significant percentage of the NOx emissions from stationary point sources in California. This significance, however, varies from district to district.

It should be noted that not all districts in California with significant stationary source IC engine emissions are included in Table 1. In some districts, stationary IC engines are not (or until recently, were not) under permit. In those cases, the Table 1 figures underestimate actual emissions. As an example, Glenn County APCD and Yolo/Solano AQMD have only recently required permits and obtained emissions estimates for most stationary IC engines, and the updated emissions estimates are not reflected in Table 1.

In other cases, some classes of IC engines with substantial emissions may be exempt from permit, and their emissions may not be reflected in Table 1. For example, engines used in agricultural operation in the San Joaquin Valley Unified APCD are exempt from permit and their emissions are not included in Table 1. Annual NOx emissions for these agricultural engines are estimated at 12,000 tons per year. This emissions estimate is greater than the NOx emissions for all permitted stationary engines in the San Joaquin Valley APCD.

IC engines generate power by combustion of an air/fuel mixture. Most stationary IC engines are used to power pumps, compressors, or electrical generators. IC engines are used in the following industries: oil and gas pipelines, oil and gas production, water transport, general industrial (including construction), electrical power generation, and agriculture.

Engines used for electrical power generation include base load power generation (generally in remote areas), resource recovery facilities in areas where waste fuels are available (such as landfills and sewage treatment facilities), portable units used as temporary sources of electrical power, and emergency generators used during electrical power outages.

There are a wide variety of IC engine designs, such as:

- Two stroke or four stroke
- Rich-burn or lean-burn
- Spark-ignited or compression-ignited
- Supercharged, turbocharged, or naturally aspirated

These engines can use one or more fuels, such as natural gas, oil field gas, digester gas, landfill gas, propane, butane, liquefied petroleum gas (LPG), gasoline, methanol, ethanol, diesel, residual oil, and crude oil. IC engines can also exhibit a wide variety of operating modes, such as:

- Emergency operation (e.g., used only during testing, maintenance, and emergencies)
- Seasonal operation
- Continuous operation
- Continuous power output
- Cyclical power output

These differences in use, design, and operating modes must be taken into account when setting standards to control emissions from IC engines.

II. SUMMARY OF THE PROPOSED DETERMINATION

The proposed RACT and BARCT limits for NOx, volatile organic compounds (VOC), and carbon monoxide (CO) are summarized in Tables 2 and 3. Different limits apply to spark-ignited rich-burn engines, spark-ignited lean-burn engines, rich-burn engines using waste gases, and compression-ignited (i.e., diesel) engines. Different limits also apply for low fuel consumption engines and high fuel consumption engines. The dividing line between low and high fuel consumption is an annual fuel consumption of 180 million BTUs for spark-ignited engines and 25,000 gallons of diesel fuel for compression (diesel) engines. For dual fuel engines, the dividing line is 3,400 million BTUs. Summaries of proposed exemptions, administrative requirements, and test methods follow the tables.

For RACT, the limits for low fuel consumption spark-ignited engines can be achieved by leaning the air/fuel mixture. For high fuel consumption spark-ignited engines, the limits are expected to be achieved by using catalysts, prestratified charge systems, or by leaning the air/fuel mixture. The limits for high fuel consumption spark-ignited lean-burn engines are expected to be achieved by leaning the air/fuel mixture, or by the retrofit of clean-burn controls to allow further leaning of the air/fuel mixture. The compression-ignited (diesel) limits are expected to be achieved by the use of injection timing retard, turbocharging and aftercooling, and the retrofit of parts from newer engines designed for low NOx emissions.

For BARCT, the limits for waste gas fueled, spark-ignited rich-burn engines are expected to be achieved by using prestratified charge systems. The low fuel consumption limits are identical to the RACT limits, and identical controls are expected to be used. For high fuel consumption spark-ignited rich-burn engines, the limits for fuels other than waste gases are expected to be achieved by using catalysts. The high fuel consumption spark-ignited lean-burn limits are expected to be achieved by the retrofit of clean-burn controls, although some engines may require the use of selective catalytic control (SCR). Controls for compression-ignited (diesel) engines consuming less than 25,000 gallons of diesel per year are expected to be the same as controls for compression-ignited engines required to meet the RACT limits. For diesel engines consuming 25,000 or more gallons of diesel per year, the BARCT limits are expected to be achieved by the use of selective catalytic reduction (SCR).

The BARCT limits and high fuel consumption thresholds reflect a cost-effectiveness threshold of $12 per pound of NOx reduced. Although the cost-effectiveness for individual engines will generally be lower than $12 per pound, in some individual cases the cost-effectiveness could exceed this figure. These RACT and BARCT limits are guidance. Districts have the flexibility to adopt IC engine rules that differ from this guidance, as long as these differences do not conflict with other applicable statutes, codes and regulations.

The full text of the proposed determination is provided in Appendix A. The technical basis for the proposed emission limits can be found in Chapters V, VI, and VII.

Table 2

Summary of Proposed RACT Standards for Stationary Internal Combustion Engines

Engine Type	% Control	PPMV at 15% O_2[1]		
	NOx	NOx	VOC	CO
Spark-Ignited Engines				
-Low Fuel Consumption[2]				
All Fuels	---	350	750	4500
-High Fuel Consumption[2]				
Rich-Burn, All Fuels	90	50	250	4500
Lean-Burn, All Fuels	80	125	750	4500
Diesel Engines	---	350	750	4500

1 For NOx, either the percent control or the parts per million by volume (ppmv) limit must be met by each engine. The percent control option applies only if a percentage is listed, and applies only to engines using exhaust controls. All engines must meet the ppmv VOC and CO limits.

2 Low Fuel Consumption refers to an annual fuel consumption of less than 180 million BTUs, while High Fuel Consumption refers to an annual fuel consumption of 180 million BTUs or greater.

Table 3

Summary of Proposed BARCT Standards for Stationary Internal Combustion Engines

Engine Type	% Control NOx	PPMV at 15% O_2[1] NOx	VOC	CO
Spark-Ignited Engines				
-Low Fuel Consumption[2]				
All Fuels	---	350	750	4500
-High Fuel Consumption[2]				
Rich-Burn, Waste Gas Fueled	90	50	250	4500
Rich-Burn, All Other Fuels	96	25	250	4500
Lean Burn, All Fuels	90	65	750	4500
Diesel Engines				
-Low Fuel Consumption[3]	---	350	750	4500
-High Fuel Consumption[3]	90	80	750	4500

[1] For NOx, either the percent control or the parts per million by volume (ppmv) limit must be met by each engine. The percent control option applies only if a percentage is listed, and applies only to engines using exhaust controls. All engines must meet the ppmv VOC and CO limits.

[2] Low Fuel Consumption refers to an annual fuel consumption of less than 180 million BTUs, while High Fuel Consumption refers to an annual fuel consumption of 180 million BTUs or greater.

[3] Low Fuel Consumption refers to an annual fuel consumption of less than 25,000 gallons of diesel fuel (less than 3,400 million BTUs for dual fueled engines), while High Fuel Consumption refers to an annual fuel consumption of 25,000 gallons or greater of diesel fuel (3,400 million BTUs or greater for dual fueled engines).

ELEMENTS APPLICABLE TO BOTH RACT AND BARCT

Exemptions

- Engines operated during emergencies or disasters to preserve or protect property, human life, or public health (e.g., firefighting, flood control)
- Engines used in agricultural operations
- Portable engines registered and controlled under the ARB statewide program
- New nonroad engines, as defined by the U.S. EPA
- Engines not used for the distributed generation of electricity, if operated 100 or fewer hours per year
- Emergency standby engines that, excluding period of operation during unscheduled power outages, operate 100 or fewer hours per year

[Note: The proposed determination exempts engines used in agricultural operations. This conforms to existing district rules, which also exempt agricultural engines. Health and Safety Code Section 42310(e) prohibits districts from requiring permits for agricultural engines. This prohibition does not preclude districts from controlling agricultural engines.]

Administrative Requirements

- Emission Control Plan
- Documentation of exemptions
- Inspection and monitoring plan
- System to monitor NOx and O_2 continuously for engines >1,000 horsepower and permitted to operate >2,000 hours per year
- Maintain records of inspections and continuous stack monitoring data for two years
- Source test every 8,760 hours of operation or two years, whichever is more frequent
- Maintain an operating log which shows, on a monthly basis, the hours of operation and fuel consumption for each engine

ELEMENTS APPLICABLE TO BOTH RACT AND BARCT
(continued)

Test Methods

- Analysis of O_2, NOx, and CO: ARB Method 100
- Analysis of VOCs: ARB Method 422

III. DESCRIPTION OF IC ENGINES

The main parts of a piston-type (also known as reciprocating) IC engine include pistons, combustion chambers, a crankshaft, and valves or ports. IC engines generate power from the combustion of an air/fuel mixture. The combusted mixture drives the piston, which is connected by a rod to the crankshaft, so that the back-and-forth motion of the piston is converted into rotational energy at the crankshaft (see Figure 1). This rotational energy drives power equipment such as pumps, compressors, or electrical generators.

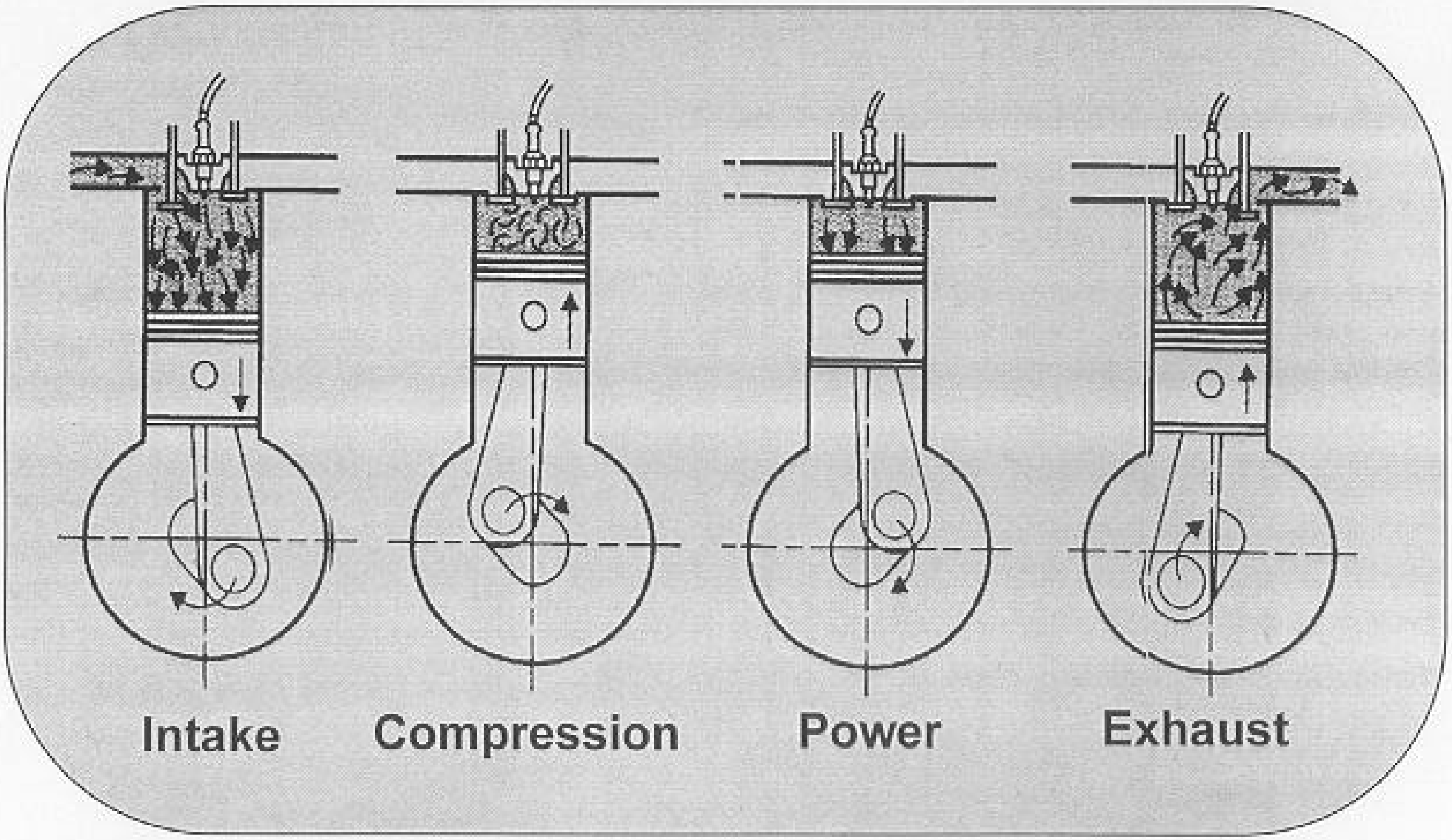
There are several key aspects of engine design and operation that influence emissions and emissions control. These include the basic design of the engine, the manner in which combustion is initiated, the type of fuel used, the introduction of intake air, the air/fuel ratio, and the operational mode of the engine. A brief description of these aspects is given below.

A. Basic Engine Design

Piston-type internal combustion engines are generally classified as either four or two stroke (the term cycle is also used instead of stroke). Four operations occur in all piston-type internal combustion engines: intake, compression, power, and exhaust. Four stroke engines require two revolutions of the crankshaft to complete all four operations, while two stroke engines require only one revolution.

In four stroke engines, a single operation is associated with each movement of the pistons (see Figure 1). During the intake stroke, the intake valves open, and gas is drawn into the combustion chambers and cylinders by the downward motion of the pistons. In the case of diesel engines, the gas is air. For most other engines, fuel is mixed with air before being introduced into the combustion chamber, and thus the gas drawn into the combustion chambers is a fuel/air mixture. At or shortly after the end of this downward movement, the valves close and the compression stroke begins with the pistons moving upward, compressing the air or air/fuel mixture. In diesel engines, once compression nears completion, the fuel is injected into the combustion chamber and spontaneously ignites. For most other engines, a spark plug ignites the air/fuel mixture. During the power stroke, the hot, high pressure gases from combustion push the pistons downward. The exhaust stroke begins when the piston nears its full downward position. At that point, the exhaust valves open, and the pistons reverse their motion, moving upward to push the exhaust gases out of the combustion chambers. Near the full upward travel of the pistons, the exhaust valves close, the intake valves open, and the intake stroke is repeated.

Figure 1
Four Stroke Engine Operation



In a two stroke engine, instead of intake valves, there are one or more ports (i.e., openings) in each cylinder wall that are uncovered as the piston nears its full downward movement (see Figure 2). Two stroke engines use either exhaust valves similar to four stroke engines, or exhaust ports located in each cylinder wall across from the intake ports. When the pistons reach their full downward travel, both the intake ports and the exhaust ports or valves are open, and the exhaust gases are swept out by the air or an air/fuel mixture that is transferred into the cylinder through the intake ports. This operation is often referred to as scavenging. In order to effect this transfer, the intake air must be pressurized. The pressurization can result from introducing the air into a sealed crankcase. Air or an air/fuel mixture is pulled into the sealed crankcase through the upward movement of the piston, and is pressurized by the downward movement of the piston. Alternatively, a supercharger or turbocharger can be used to compress the intake air. The example in Figure 2 shows a supercharger used for this purpose. The compression and power strokes for a two stroke engine are similar to those for a four stroke engine.

B. Combustion Initiation

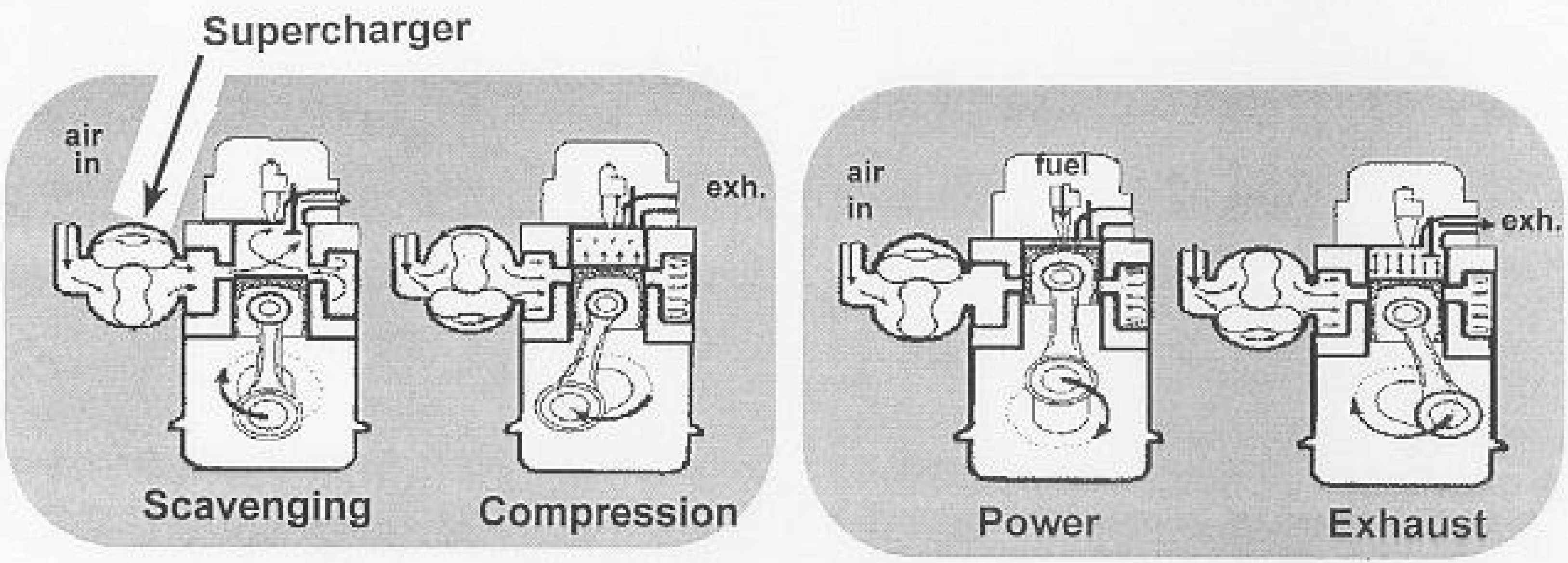
Combustion in IC engines is initiated by either a spark plug or by compression heating. In spark-ignited (also called Otto cycle) engines, the fuel is usually mixed with intake air before introduction into the combustion chamber, resulting in a relatively homogeneous air/fuel mixture in the combustion chamber. Once the spark plug initiates combustion, the homogeneous mixture propagates the flame throughout the combustion chamber.

Combustion can also be initiated through the heat generated by compression. This engine design is called a compression-ignited (or Diesel cycle) engine. During the compression stroke, the intake air is compressed, which increases the temperature of this air substantially. Near the completion of the compression stroke, fuel is injected into the combustion chamber under high pressure to promote atomization. The atomized fuel spontaneously ignites upon contact with the hot air in localized regions that have the proper air/fuel ratio.

C. Type of Fuel

In general, spark-ignited (SI) and compression-ignited (CI) engines use different fuels. SI engines can use natural gas, landfill gas, digester gas, field gas, refinery gas, propane, methanol, ethanol, gasoline, or a mixture of these fuels. Natural gas consists almost exclusively of methane. Field gas refers to the raw gas produced from oil or gas production fields. Refinery gas refers to the gas generated by oil refinery processing. Field gas and refinery gas consist of mostly methane, but contain more of the heavier gaseous hydrocarbon compounds than natural

Figure 2
Two Stroke Engine Operation



gas. Landfill gas is generated from the decomposition of waste materials deposited in landfills. Landfill gas is typically about one-third methane, with the remaining two-thirds being mostly inert gases such as carbon dioxide and nitrogen. Digester gas is generated from the anaerobic digestion of solids at sewage treatment plants. Digester gas is typically about two-thirds methane, while the remaining one-third is mostly inert gases such as carbon dioxide.

Significant amounts of gaseous sulfur compounds may also be present in landfill and digester gas. The sulfur content of the fuel is important, as exhaust catalysts may be adversely affected by high levels of sulfur.

For CI engines, the most common fuel is diesel oil, although some very large CI engines are designed to also use crude oil or residual fuel oil. This proposed determination uses the terms CI engine and diesel engine interchangeably.

Some CI engines are "dual fuel" engines, using both diesel fuel and supplemental fuel. This supplemental fuel is usually natural gas, although other fuels are sometimes used.

D. Introduction of Intake Air

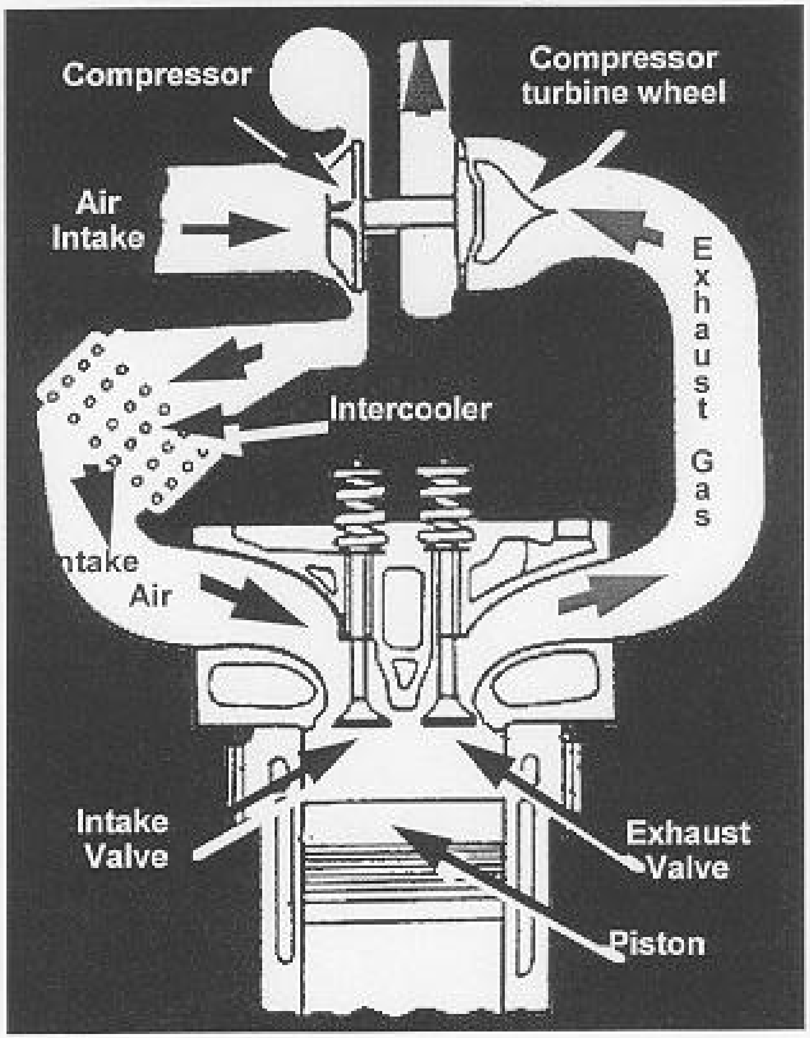
On many engines, the intake air is compressed by a supercharger or turbocharger before it enters the combustion chambers. This compression can increase engine power substantially.

The major parts of a turbocharger consist of a turbine and compressor (see Figure 3). Exhaust gases from the combustion chamber, which are still under greater than atmospheric pressure, pass through the exhaust pipe into the turbine, causing the turbine blades to spin. The turbine is connected by a shaft to a compressor. Intake air is directed into the compressor, where it is pressurized before passing through the intake manifold into the combustion chamber. The turbocharger allows the engine to pass a greater mass of air through the combustion chambers, which allows more fuel to be added and more power to be produced. Turbocharging also improves the efficiency of an engine in converting fuel into power.

Superchargers work in a similar fashion to turbochargers, except a mechanical power drive off the engine rather than exhaust gas powers the compressor (see Figure 2). Less power is required to run a turbocharger than a comparable supercharger, and therefore turbocharged engines tend to be slightly more efficient than supercharged engines.

Engines not equipped with turbochargers or superchargers are referred to as naturally aspirated. Two stroke engines sometimes use superchargers to displace exhaust with intake air,

Figure 3
Turbocharger



but this design generally does not result in any significant pressurization of the intake air, and such engines are also classified as naturally aspirated.

E. Air/Fuel Ratio

Another basic engine parameter is the air/fuel ratio. When the air/fuel ratio provides exactly enough oxygen to fully oxidize the fuel, this ratio is referred to as stoichiometric. Engines that use air/fuel ratios that are somewhat higher than stoichiometric introduce excess air into the combustion process. Such engines combust a lean mixture, and contain significant amounts (i.e., more than 4 percent) of oxygen in their exhaust stream. These engines are often referred to as "lean-burn" engines. Engines that contain less than about 4 percent oxygen in their exhaust stream are referred to as "rich-burn" engines.

All CI engines and most turbocharged spark-ignited engines are lean-burn, while naturally aspirated SI engines are generally rich-burn. Lean-burn engines tend to be more efficient but larger in size and higher in capital cost than rich-burn engines of the same power output. Also, smaller engines tend to be rich-burn, while larger engines tend to be lean-burn.

Spark-ignited IC engines exhibit peak thermal efficiency (and also peak NOx emissions) at an air/fuel ratio that is about 6 to 12 percent leaner than stoichiometric. Efficiency (and NOx emissions) decrease if the mixture becomes leaner or richer than this peak efficiency ratio (see Figure 4). If the mixture is richened, NOx emissions can be reduced to about 50 percent of their peak value before encountering problems with excessive emissions of CO, VOC, and possibly smoke. If the mixture is leaned from the peak efficiency air/fuel ratio, NOx reductions exceeding 50 percent of peak values are possible.

As the mixture is leaned, at some point the engine will have difficulty in initiating combustion of the lean air/fuel mixture. One of the more popular methods of overcoming ignition difficulties with lean mixtures is to incorporate a precombustion chamber into the engine head (see Figure 5). A precombustion chamber is a small combustion chamber which contains the spark plug. A rich mixture is introduced into the precombustion chamber, which is ignited by the spark plug. Passageways from the precombustion chamber to the main combustion chamber allow the flame front to pass into and ignite the lean mixture in the main combustion chamber. Precombustion chambers can be used on both CI and SI engines. When used on CI engines, a fuel injector replaces the spark plug in the precombustion chamber.

Another method used to assist combustion of lean mixtures (especially in smaller engines) is to redesign the intake manifold and combustion chamber to promote more thorough

Figure 4

Emissions as a Function of Air to Fuel Ratio

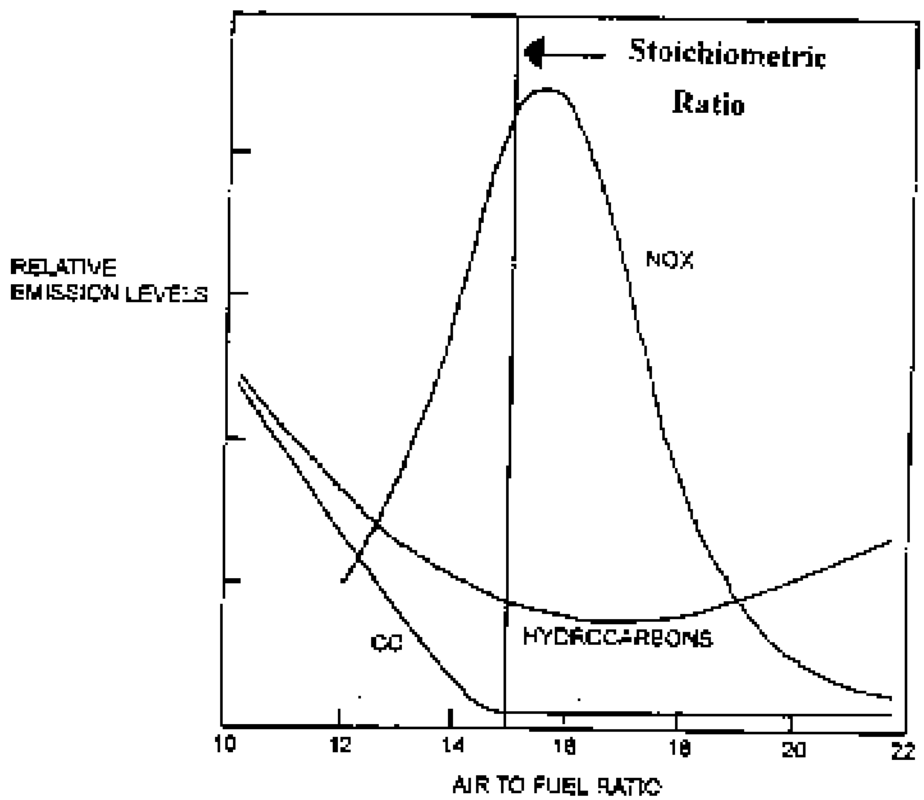
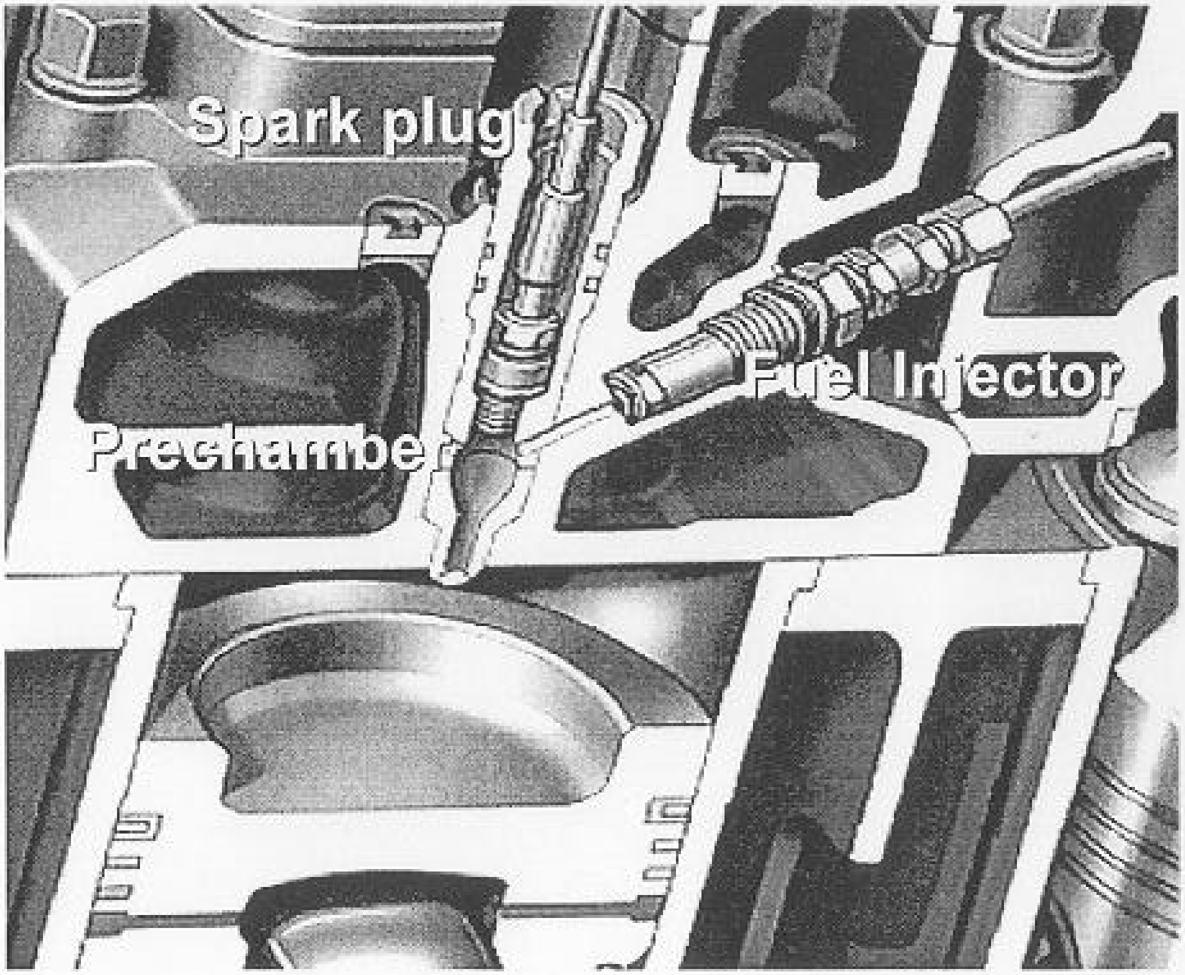


Figure 5
Pre-Chamber System



Courtesy Waukesha

mixing, so that a more uniform air/fuel mixture is present in the combustion chamber. A third method is to use an improved ignition system that sparks either more frequently or continuously.

F. Operational Mode

Reciprocating IC engines can be used in several operational modes. In many cases, they are used continuously under a constant power load, shutting down only when there is a breakdown, or when maintenance or repair work is required. Other engines operate cyclically, changing their power output on a regular, frequent schedule. One of the more common cyclic applications is an oil well pump, where an engine may operate at load for a time period varying from several seconds to about 20 seconds, followed by an equal amount of time operating at idle.

Some engines may operate continuously, but for only part of the year. In many cases, this intermittent operation is seasonal. In other cases, engines are portable, and are used only for a specific, short-term need. In still other cases, engines are used infrequently, for emergency purposes. Such engines may operate for no more than a few hours per year during an emergency, and are also tested routinely, typically for less than an hour once a week. Other engines may operate in modes that combine the characteristics of cyclic and continuous operations.

The operational mode of the engine is an important consideration when adopting control regulations. The operational mode may impact operating parameters such as exhaust gas temperature, which often must be taken into account when designing and applying controls. The operational mode may also affect the impact of emissions on air quality. For instance, an engine that operates only during summer, which is the peak ozone season, will have a much greater impact on ambient air quality violations than an engine with the same annual emissions that operates year round.

IV. SUMMARY OF IC ENGINE CONTROLS

The combustion of hydrocarbon fuels in IC engines results in emissions of NOx, CO, VOC, particulate matter, and sulfur oxides (SOx). The pollutant of primary concern from stationary IC engines is NOx. Emissions of NOx are far greater than any other pollutant for engines burning diesel or natural gas. The vast majority of stationary IC engines burn either diesel or natural gas.

There are probably more different types of controls available to reduce NOx from IC engines than for any other type of NOx source. These controls include the following general categories: combustion modifications, fuel switching, post combustion controls, and replacement of the engine with a new, low emissions engine or an electric motor. A new, low emissions engine may use several combustion modifications to reduce emissions, and may also use fuel switching.

Combustion modifications include injection or ignition timing retard, leaning of the air/fuel ratio, modified injectors, optimization of the internal engine design, turbocharging or supercharging with aftercooling, and exhaust gas recirculation. In the case of leaning the air/fuel ratio, this is generally done in combination with other techniques which allow extremely lean ratios. These other techniques include "clean burn" modifications, ignition system improvement, prechamber design, and prestratified charge system.

Fuel switching includes the substitution of water/diesel combinations for diesel, methanol for either natural gas or diesel, and clean diesel for conventional diesel. Post combustion controls include nonselective catalytic reduction and selective catalytic reduction.

Table 4 summarizes the applicability and effectiveness of the NOx control methods for stationary engines. A more detailed description of controls for stationary IC engines can be found in Appendix B.

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Table 4

Summary of NOx Controls For Stationary IC Engines

Reduction Control Method	Applicability[1]	NOx Effectiveness
Combustion Modifications		
Injection Timing Retard	CI Engines	5-30%
Ignition Timing Retard	SI Engines	15-30%
Prestratified Charge	Rich-burn SI Engines	80+%
Lean Air/Fuel Ratio	SI Engines	80+%[2]
Modified Injectors	CI Engines	50%[2]
Optimized Engine Design	CI Engines	50+%[2]
Turbocharging or Supercharging With Aftercooling	All Engines	3-35%
Exhaust Gas Recirculation	All Engines	30%
Fuel Substitution		
Water/Diesel Mixture	CI Engines	up to 60%
Methanol	Natural Gas Engines	30%
	CI Engines	80%
Clean Diesel	CI Engines	7%
Post-Combustion Controls		
Nonselective Catalytic Reduction	SI Rich-Burn Engines	90+%
Selective Catalytic Reduction	CI, SI Lean-Burn Engines	80+%
Replacement with Low Emissions Engine Or Electric Motor	All Engines	90-100%[3]

[1] CI = compression-ignited
SI = spark-ignited
[2] When combined with other NOx reduction methods
[3] For replacement with an electric motor, emissions are reduced 100 % at the IC engine location, although emissions at power plants may increase.

V. BASIS FOR PROPOSED RACT EMISSIONS LIMITS

A summary of the proposed RACT determination can be found in Chapter II. The full text of the proposed RACT determination can be found in Appendix A.

It is generally understood that RACT is the application of demonstrated technology to reduce emissions. "Demonstrated" means a particular limit has been achieved and proven feasible in practice. This demonstration need not take place in California. The demonstration also need not be performed on every make and model of IC engine, as long as there is a reasonable likelihood that the technology will be successful on these other makes and models.

Different NOx emissions limits are applicable to spark-ignited engines having low fuel consumption and high fuel consumption. For spark-ignited engines, the fuel consumption cutoff of 180 million BTUs per year equates to a 50 brake horsepower engine operating between 300 and 400 hours per year. For diesel engines, the fuel consumption cutoff of 25,000 gallons equates to a 500 brake horsepower engine operating between 900 and 1,000 hours per year.

A. Spark-Ignited Rich-Burn Engines

The proposed RACT emission limits for spark-ignited engines having low annual fuel consumption are based on data from the Santa Barbara County APCD and other sources concerning the effect of leaning the air/fuel ratio on engines using natural gas or field gas. In the case of Santa Barbara, engines were able to meet a NOx limit of 50 ppmv by leaning the mixture. Other information indicates that engines burning natural gas or field gas can be leaned to reduce NOx emissions below 300 ppmv.

We acknowledge that it may not be cost-effective for some low fuel consumption engines to meet the recommended NOx limit of 350 ppmv. Because of the range of makes and models of engines and applications, we recommend that such engines be identified by districts during the rule adoption process. At that time, limits that differ from those in this proposed determination can be proposed.

The proposed RACT emission limits for spark-ignited rich-burn engines having high annual fuel consumption are based on Ventura County APCD's Rule 74.9 that was in effect between September 1989 and December 1993 (this rule was superseded by a more effective version of Rule 74.9 in December 1993). The 1989-1993 version of this rule required all affected engines to meet applicable limits by 1990. For natural gas-fired rich-burn engines, this NOx limit is 50 parts per million by volume (ppmv), corrected to 15 percent oxygen and dry conditions.

Alternatively, rich-burn engines can meet a 90 percent NOx reduction requirement.

The Ventura County rule allowed the ppmv limits to be increased for engines exhibiting efficiencies greater than 30 percent. However, there are few cases where such efficiency adjustments would increase the allowable emissions significantly. For example, natural gas-fired engines rarely exceed the mid-30s in percentage efficiency, and most of these engines probably are less than 30 percent efficient. In addition, districts that include an efficiency adjustment in their IC engine rules have rarely found a need to use this adjustment to meet rule requirements. This proposed determination does not include an efficiency adjustment. Such an adjustment increases the complexity of the determination, and would complicate enforcement. In many cases, it is difficult to determine the efficiency of an engine. The manufacturer's rated efficiency could be used, but in some cases this information may not be available. Even if this information is available, the efficiency of an engine in the field may differ significantly from the manufacturer's rating due to differences in air density, temperature, humidity, condition of the engine, and power output. The proposed RACT emissions limits can be met without an efficiency adjustment if controls are properly designed, maintained, and operated.

Appendix D summarizes a large number of source tests from Ventura County for the years 1986 through 1992. Results of these tests on rich-burn engines are compared to the Ventura IC engine rule applicable at the time (i.e., 50 ppmv NOx or 90 percent reduction). Included in this database were a few tests on engines to determine baseline values or emission reduction credits. These engines were not controlled and were not required to meet the rule's emissions limits. Excluding tests conducted to determine baseline values or emission reduction credits leaves 595 tests on rich-burn engines. Only 22 of these tests exceeded the applicable NOx limit. In almost all cases, engines that violated the limit passed several other source tests before and after the violation. No particular engine make or model appeared to have a significant problem in attaining the applicable NOx limit. These source tests covered 30 different models of engines made by seven different manufacturers.

From the mid-1980s to the mid-1990s, approximately 280 of 360 stationary engines were removed from service in Ventura County. Many of the removal engines were first retrofitted with controls and were in compliance when they were removed. Though Ventura County's IC engine rule may have contributed to the reduction in the number of stationary IC engines, other areas of the State that did not have a rule controlling NOx emissions from existing stationary engines also experienced significant reductions in stationary engines during the same time period. Most of these engines were used in oil and gas production activities. This reduction in numbers may reflect an overall general reduction in oil and gas production in the State. It may also reflect the impact of new source review. New source review is a collection of emissions and mitigation requirements that must be met before a new or existing stationary source of emissions can be built or modified in the State. New source review may have encouraged the use of electric motors rather than IC engines for new or modified production activities. In addition, new source review may have encouraged the shutdown or replacement of existing IC engines to generate emissions offsets for new or modified production activities.

Based on these data, it appears that the proposed RACT emission levels for rich-burn engines having high annual fuel consumption are achievable for a wide variety of gaseous-fueled engines.

It is expected that the most common control method to be used to meet the proposed RACT limits for rich-burn engines having high annual fuel consumption will be the retrofit of nonselective catalytic reduction (NSCR) controls. For rich-burn engines using waste-derived fuels, where fuel contaminants may poison the catalyst, the most common control method is expected to be the use of prestratified charge controls.

Cyclically operated (cyclic) engines have characteristics that may affect the effectiveness of controls. These characteristics include low exhaust gas temperatures (since the engines spend significant periods of time at idle) and rapid fluctuations in power output. Cyclically operated rich-burn engines have met the high fuel consumption RACT limits either by using NSCR or by leaning the air/fuel mixture. Both of these control methods have been used successfully on a number of cyclically operated engines in Santa Barbara County. Source tests of NSCR-equipped cyclic engines in Santa Barbara County have shown that these engines can be effectively controlled without air/fuel controllers. In many cases, the air/fuel ratio controllers that are part of the control system have slow response times, making NSCR ineffective on cyclic engines. Table 5 summarizes the results of source tests on cyclically operated engines in Santa Barbara County. These tests were conducted from 1992 through 1994. All engines at Site A used NSCR to control NOx emissions. All engines at other sites used leaning of the air/fuel mixture to control NOx. These engines represent two different manufacturers and six different models.

Table 5

**Summary of NOx Source Testing of Cyclically Operated Engines
Santa Barbara County**

					Emissions in ppmv		
Site	Engines	Tests	Engine Size	Operating Capacity	NOx	CO	VOC
A	27	5	195 hp	50-75%	4-14	647-2445	2-35
B	4	9	131 hp	20-40%	12-35	165-327	29-552[1]
C	16	16	39-46 hp[2]	50-100%	8-28	129-291	25-48
D	17	28	39-49 hp[2]	30-75%	7-33	154-406	31-196

1 One engine exceeded the 250 ppmv limit. After repairs, this engine was retested 6 weeks later and was found to be in compliance.

2 Engines were derated to the listed engine size.

B. Spark-Ignited Lean-Burn Engines

The basis for the proposed RACT emission limits for high fuel consumption spark-ignited lean-burn engines is the same as for high fuel consumption rich-burn engines: Ventura County APCD's Rule 74.9 that was in effect between September 1989 and December 1993. For natural gas-fired lean-burn engines, this NOx limit is 125 ppmv, corrected to 15 percent oxygen and dry conditions. Alternatively, lean-burn engines can meet an 80% NOx reduction requirement.

Appendix D summarizes a large number of source tests from Ventura County from the years 1986 through 1992. Results of these tests on lean-burn engines were compared to the limits of Ventura County's IC engine rule applicable at the time (i.e., 125 ppm NOx or 80 percent reduction). Excluding tests conducted to determine baseline values or emission reduction credits, there were 236 tests on lean-burn engines. Only 15 of these tests exceeded the applicable NOx limit. In almost all cases, engines that violated the limit passed several other source tests before and after the violation. No particular engine make or model appeared to have a significant problem in attaining the applicable NOx limit. These source tests covered twelve different models of engines made by five different manufacturers.

Based on these data, we conclude that the proposed RACT emission levels for high fuel consumption lean-burn engines are achievable for a wide variety of gaseous-fueled engines.

We expect the most popular control method used to meet the proposed RACT limits for high fuel consumption lean-burn engines will be the retrofit of "clean" burn engine modifications. These modifications will probably include the retrofit of precombustion chamber heads. In cases where these modifications have not been developed for a particular make and model of engine, selective catalytic reduction (SCR) may be used as an alternative.

C. Compression-Ignited Engines

The proposed NOx RACT limit for compression-ignited (diesel) engines is based on data from the San Diego County APCD. San Diego, in the development of a revised IC engine rule, has found a 350 ppm NOx limit to be appropriate for diesel engines in their district.

We acknowledge that it may not be cost-effective for some diesel engines to meet the recommended NOx limit of 350 ppmv. Because of the range of makes and models of engines and applications, we recommend that such engines be identified by districts during the rule adoption process. At that time, limits that differ from those in this proposed determination can be proposed.

The VOC and CO limits from diesel engines are based on recently adopted IC engine rules controlling diesel engines in the San Joaquin Valley Unified Air Pollution Control District, the Yolo-Solano Air Quality Management District, the El Dorado County Air Pollution Control District, and the Kern County Air Pollution Control District.

We expect the control methods employed to meet the proposed RACT limits will include one or more of the following: injection timing retard, turbocharging with aftercooling, and electronically controlled injectors. In many cases, the diesel engine is a derivative of an on-road truck engine, and NOx controls developed for the on-road version of the engine can be retrofitted to meet the proposed RACT limits.

VI. BASIS FOR PROPOSED BARCT EMISSIONS LIMITS

A summary of the proposed BARCT determination can be found in Chapter II. The full text of the proposed BARCT determination can be found in Appendix A.

The Health and Safety Code Section 40406 defines best available retrofit control technology (BARCT) as "an emission limitation that is based on the maximum degree of reduction achievable, taking into account environmental, energy, and economic impacts by each class or category of source." Control technology must be available by the compliance deadline that has achieved or can achieve the BARCT limits, but these limits do not necessarily need to have been demonstrated on IC engines. A technology can meet the definition of BARCT if it has been demonstrated on the exhaust gases of a similar source (such as a gas turbine), there is a strong likelihood that the same technology will also work on exhaust gases from IC engines, and systems designed for IC engines are available from control equipment vendors.

A. Spark-Ignited Rich-Burn Engines

The proposed BARCT emission limits for low annual fuel consumption spark-ignited engines are the same as the RACT limits for this category of engine, and the basis is also the same (see page 22).

The proposed BARCT emission limits for high fuel consumption rich-burn engines are based on the current version (adopted December 1993) of Ventura County APCD's Rule 74.9, the Federal Implementation Plan for the Sacramento area, and the Sacramento Metropolitan Air Quality Management District's Rule 412. These NOx limits are 25 ppmv or 96 percent reduction for most rich-burn engines, and 50 ppmv or 90 percent reduction for rich-burn engines using waste gases as fuel. Best available control technology (BACT) determinations of the South Coast AQMD and ARB's BACT Clearinghouse meet or exceed the proposed BARCT limits.

The Ventura County source test data referenced earlier (page 23) indicates that 66 percent of the tests (i.e., 405 out of 616 tests) on rich-burn engines operating on natural gas or oil field gas met the proposed BARCT NOx limit of 25 ppmv. These engines used either NSCR type catalysts or prestratified charge controls. Engines using prestratified charge controls met the limit less often (32 percent, or 16 out of 50 tests) than engines using catalysts (69 percent, or 389 out of 566 tests). The controls for these rich-burn engines were designed to meet a 50 ppmv or 90 percent reduction limit, not a 25 ppmv or 96 percent NOx reduction limit as proposed in the proposed BARCT determination. Better NOx emission reduction performance can be anticipated if controls are designed to meet a 25 (rather than 50) ppmv limit.

A separate BARCT NOx limit is proposed for rich-burn engines fueled by waste gases (e.g., sewage digester gas, landfill gas). This limit, 50 ppmv or 90 percent reduction, is the same as the proposed RACT limit for rich-burn engines. Source tests of rich-burn engines using waste gases indicate only 28 percent (9 of 32 tests) demonstrated compliance with a NOx limit of 25 ppmv. However, all of these tests demonstrated compliance with a 50 ppmv limit. The waste gas engines that were tested used prestratified charge controls because the application of NSCR to waste gas fueled engines has often been unsuccessful. NSCR catalysts often have problems with plugging and deactivation from impurities in waste gases.

It is expected that the most popular control method used to meet the proposed BARCT limits for high fuel consumption rich-burn engines using fuels other than waste gases will be NSCR with air/fuel ratio controllers. For engines using waste gases, the use of prestratified charge controls are expected to be the most popular control method.

For high fuel consumption engines equipped with catalysts intended to achieve 25 ppmv NOx, the catalysts are expected to differ from catalysts intended to achieve 50 ppmv NOx through the use of one or more of the following: larger catalysts, greater amounts of active materials in the catalysts, and more precise air/fuel ratio controllers. In addition, closer tolerances, more frequent inspections, and monitoring of a greater number of parameters as outlined in the compliance and inspection procedures will probably be required to maintain the higher performance required to meet the proposed BARCT limits.

B. Spark-Ignited Lean-Burn Engines

The proposed BARCT emission limits for high fuel consumption spark-ignited lean-burn engines are based on the current version (adopted December 1993) of Ventura County APCD's Rule 74.9, the Federal Implementation Plan for the Sacramento area, and the Sacramento Metropolitan Air Quality Management District's Rule 412.

We propose a 65 ppmv or 90 percent reduction level as the BARCT NOx limit. This proposed level is identical to the level in the proposed Federal Implementation Plan for the Sacramento area, and is also identical to the level found in Sacramento Metropolitan AQMD's Rule 412. This level is less effective than the current Ventura County APCD's Rule 74.9 NOx limit of 45 ppmv or 94 percent control. However, the Ventura County APCD's limit includes an efficiency correction that can allow a NOx ppmv limit higher than 45. The proposed determination does not include an efficiency correction. In addition, only 35 percent of the Ventura County APCD’s source tests (84 of 241 tests) showed compliance with a 45 ppmv or 94 percent control NOx limit. On the other hand, the Ventura County APCD’s source test data show that 64 percent of the source tests (153 of 241) for lean-burn engines met a NOx limit of

65 ppmv or 90 percent reduction. These engines were required to meet a less effective 125 ppmv or 80 percent reduction requirement. The NOx reduction performance for engines using controls designed to meet the proposed BARCT limit is expected to be better than that indicated by the Ventura County source test data.

It is expected that the most common control method used to meet the proposed BARCT emission limit for high annual fuel consumption spark-ignited lean burn engines will be the retrofit of “clean” burn engine modifications (e.g., precombustion chamber heads). Other techniques may also be used to supplement these retrofits, such as ignition system modifications and engine derating. For engines that do not have "clean" burn modification kits available, selective catalytic reduction (SCR) may be used as an alternative to achieve the BARCT emission limits.

C. Compression-Ignited Engines

For compression-ignited (diesel) engines, the proposed determination proposes different BARCT limits for low and high fuel consumption engines. The low annual fuel consumption limits are identical to the RACT limits for diesel engines, and the basis is also identical.

For the high annual fuel consumption diesel engines, the NOx emission limit is 80 ppmv or 90 percent control. The basis for this limit is the current version (adopted December 1993) of Ventura County’s Rule 74.9, the Federal Implementation Plan for the Sacramento area, and the Sacramento Metropolitan Air Quality Management District’s Rule 412. Control requirements for newly installed or modified stationary diesel engines also support this emission limit.

The most popular control methods for meeting the emission limits for low annual fuel consumption diesel engines are expected to be the same as the methods used to meet the proposed RACT limits for diesel engines. The most popular control method for high fuel consumption diesel engines is expected to be selective catalytic reduction (SCR).

In the past, SCR has been less effective in reducing emissions from diesel engines that operate under a varying load. Applications of SCR on engines operating at a continuous power output have been successful. The main reason for this difference is that most SCR systems inject ammonia based on the output of a continuous emissions monitor, and such monitors are relatively slow in reacting to changes in NOx emissions. However, recent improvements in electronics have included faster reacting feedback and feed forward controls, along with monitoring of other important engine parameters, and these improvements have been successful.

SCR is not effective on diesel engines that operate for long periods at idle or low power outputs, such as engines used to operate cranes. For this reason, the proposed BARCT determination applies the low annual fuel consumption emission limits to diesel crane engines. On a case-by-case basis, districts may find other applications where the retrofit of SCR may not be effective, and less effective NOx limits are warranted.

VII. BASIS FOR PROPOSED DETERMINATION ELEMENTS COMMON TO BOTH RACT AND BARCT

Both the proposed RACT and BARCT determinations include identical limits for CO and VOC. Other elements that are identical include alternatives to controlling engines, an alternative form for the limits (i.e., percentage reduction), applicability, and exemptions.

A. CO Limits

The proposed determination’s limit for CO is 4,500 ppmv. The 4,500 ppmv limit is the highest CO limit in any district IC engine rule in California. Most districts have a 2,000 ppmv CO limit. The 4,500 ppmv CO limit in the proposed determination was chosen since the main concern for emissions from IC engines has been on NOx, and some controls for NOx tend to increase CO emissions. The 4,500 ppmv CO limit should allow the proposed determination's NOx limits to be met more easily and economically. In most cases, the proposed determination’s NOx limits will be met either by the use of three-way catalysts or a leaner air/fuel mixture. Either of these techniques should readily achieve a CO level of 4,500 ppmv.

In general, vehicles have been found to be the major source of CO in areas that are nonattainment for CO, and stationary sources do not contribute significantly to the nonattainment status. However, areas that are nonattainment for CO should assess the impact of stationary engines on CO violations, and should consider adopting a lower CO limit than 4,500 ppmv.

B. VOC Limits

VOC limits are included in the proposed determination because VOC emissions, like NOx emissions, are precursors to the formation of ozone and particulate matter. For stationary engines, the mass and impact of VOC emissions tend to be much lower than NOx emissions. However, several NOx controls tend to increase VOC emissions. The proposed determination's VOC limits are designed to assure that VOC increases from NOx controls do not become excessive.

In addition, the proposed determination's VOC limits help assure that engines are properly maintained. If an engine is misfiring or has other operational problems, VOC emissions can be excessive.

The proposed determination’s limit for VOC is 250 ppmv for rich-burn engines and 750 ppmv for lean-burn and diesel engines. The 250 ppmv limit for rich-burn engines is readily achievable through the use of three-way catalysts or other NOx control methods involving leaning of the air/fuel mixture. A higher limit is proposed for lean-burn engines, as VOC concentrations tend to increase when such engines are operated at the extremely lean levels needed to achieve the determination's NOx limits. These VOC limits are equal to the highest limits included in any district IC engine rule in California.

In cases where a district requires further VOC reductions to achieve the ambient air quality standards, the adoption of VOC limits more effective than those in the proposed determination should be considered. More effective VOC limits can be achieved through the use of oxidation catalysts without impacting NOx reduction performance.

C. Other Control Options

In addition to combustion modifications, exhaust controls, and use of alternative fuels, other control options can be used to meet the proposed RACT and BARCT limits.

All proposed RACT and BARCT limits can also be met by replacement of the IC engine with an electric motor or a new controlled engine. The new controlled engine would use combustion modifications, exhaust controls, or an alternative fuel similar to an existing retrofitted engine. However, since the engine is new, greater design flexibility is usually available to engineer a more efficient engine and effective control package.

Another option for meeting the proposed RACT and BARCT limits is available for some engines where parts are available to convert a rich-burn engine into a lean-burn engine, or a lean-burn engine into a rich-burn engine. In the case of engines converted to lean-burn, improved engine efficiencies may reduce overall costs compared to controlling the rich-burn engine. In the case of engines converted to rich-burn, the rich-burn controls may be much lower in cost than the lean-burn controls.

D. Alternative Form of Limits

For engines in the high fuel consumption category, the proposed determination provides a choice of two NOx alternatives: operators must meet either a percent reduction or a parts per million by volume (ppmv) limit. The reason for the alternatives is that exhaust controls typically reduce NOx by a certain percentage, regardless of the initial NOx concentration. Thus, for engines inherently high in NOx, the ppmv limit may be difficult to achieve when using exhaust controls. Providing a ppmv and percent reduction option allows engine owners or operators a greater degree of flexibility in choosing appropriate controls.

Use of the percentage reduction option is limited to engines using add-on control devices that treat the exhaust gas stream. Determining compliance when such exhaust controls are used is relatively straightforward, as NOx concentrations can be measured before and after the control device. In contrast, for controls based on engine changes or fuel changes, it is generally extremely difficult to determine an accurate percentage reduction. A baseline concentration must be established, and this baseline will be a function of numerous engine operating parameters such as air/fuel ratio, ignition or injection timing, and power output. It would be difficult to verify that all of these engine parameters are representative of normal engine operation. In addition, other parameters will affect emissions, such as air density, temperature, humidity, and condition of the engine. Not all of these factors can be quantified, and it would be impossible to accurately match or correct for these parameters in subsequent source tests used to determine the percentage reduction in emissions.

Except for the optional percentage reduction for NOx, the proposed determination uses limits expressed in parts per million by volume (ppmv). These limits could have been expressed in units of grams per brake horsepower-hour. However, use of limits in terms of grams per brake horsepower-hour would require engines to be simultaneously tested for emissions and horsepower. This would increase costs for compliance verification, and for that reason limits expressed in terms of grams per brake horsepower-hour are not recommended.

E. Applicability

[Note: The proposed determination exempts engines used in agricultural operations. This conforms to existing district rules, which also exempt agricultural engines. Health and Safety Code Section 42310(e) prohibits districts from requiring permits for agricultural engines. This prohibition does not preclude districts from controlling agricultural engines.]

This proposed determination is applicable to stationary engines that have or have had a continuous power rating equal to or greater than 50 brake horsepower. This wording was chosen to avoid circumvention of the rule through derating of the engine's power. The 50 horsepower applicability limit is based on cost-effectiveness considerations. Cost-effectiveness is not significantly different for an engine that is just over 50 horsepower in comparison to that same engine if derated to just under 50 horsepower. In several cases, districts have a substantial number of engines just over 50 horsepower. If derating is allowed, many of the emission reductions these districts expected from an IC engine rule may not be realized.

In some cases, an engine's power rating may be suspect or unknown. To assure that engines exceeding 50 brake horsepower are not exempt, engines with a maximum fuel consumption rate above a specified level are also subject to controls. These fuel consumption rates are 0.37 million BTUs per hour for turbocharged or supercharged diesel engines, 0.39 million BTUs per hour for naturally aspirated diesel engines, and 0.52 million BTUs per hour for spark ignited engines. These fuel consumption levels correspond to engines rated at approximately 50 brake horsepower.

F. Exemptions

1. Engines Used During Disasters or Emergencies

Engines are exempt from the proposed determination when used during a disaster or state of emergency, provided that they are being used to preserve or protect property, human life, or public health. Reasons for including this exemption are obvious. If controls fail on an engine used during a disaster, without this exemption the operator is faced with fines for noncompliance if operations continue, or the loss of property, human life, or public health if the engine is shut down. Exempting the engine from the rule eliminates this dilemma.

2. Engines used in Agricultural Operations

Engines are exempt from the proposed determination if they are used directly and exclusively by the owner or operator for agricultural operations necessary for the growing of crops or raising of fowl or animals. This exemption conforms to district rules, which also exempts agricultural engines. Health and Safety Code Section 42310(e) prohibits districts from requiring permits for agricultural engines.

[Note: This Health and Safety Code prohibition does not preclude districts from controlling agricultural engines. We are soliciting comments on the appropriateness of applying this proposed determination to agricultural engines.]

3. Portable Engines

This proposed determination also exempts engines if they are portable units registered under the State control program described under Article 5, Sections 2450-2465, Title 13, California Code of Regulations. In general, districts have jurisdiction over engines that are stationary sources. However, Health and Safety Code Sections 41750 through 41755 require the ARB to develop a registration program and emissions limits for portable engines (see

Chapter XI). Owners or operators of portable engines who decide to take part in this registration and control program are exempt from meeting the requirements of district rules and regulations.

4. New Nonroad Engines

To conform to federal law, the proposed determination exempts new nonroad engines. Under the federal Clean Air Act Amendments of 1990, districts are prohibited from adopting or enforcing emission standards for some categories of new nonroad engines. For other categories of new nonroad engines, control can be delegated to the ARB. See Chapter XI for further details.

5. Engines Operated No More Than 100 Hours Per Year

Engines that are not used for distributed generation of electrical power are exempt if they operate 100 hours or fewer per year. Distributed generation refers to the practice where an IC engine is operated to produce electrical power, and this power is either fed into the electric utility grid or displaces utility electric power purchased by an industrial or commercial facility. This term also refers to the operation of an IC engine that is part of a mechanical drive system (e.g., water pump, conveyor belt) consisting of at least one IC engine and one electric motor, where the system can be powered either by the electric motor(s) or the IC engine(s).

IC engines used for distributed generation are not exempt, regardless of the number of hours of operation per year. The reason for this restriction is to assure that exempt engines will not operate simultaneously on some of the highest ozone days of the year (see the following discussion on the emergency standby engine exemption).

6. Emergency Standby Engines

The exemption for emergency standby engines is limited to engines operating no more than 100 hours per year, excluding emergencies or unscheduled power outages. Emergency standby engines are typically operated for less than an hour each week to verify readiness. Additional operation may be periodically required for maintenance operations. A limit of 100 hours per year allows a reasonable number of hours for readiness testing and about 50 hours per year for maintenance and repairs.

The definition of emergency standby engine excludes engines that operate for any other purpose than emergencies, unscheduled power outages, periodic maintenance, periodic readiness testing, and scheduled power outages for maintenance and repairs on the primary power system. The purpose of these limitations is to assure that these engines do not operate during nonemergencies to displace or supplement utility grid power for economic reasons.

The current electric utility restructuring that is occurring in California changes the pricing of electricity and the incentives applicable to commercial and industrial facilities. Under restructuring, commercial and industrial customers are able to purchase electricity on the spot market. Spot prices are relatively low during the night, but much higher when the demand for power is at a peak. This peak is typically on hot summer days, when some of the highest ozone concentrations of the year are recorded.

Restructuring allows commercial and industrial facilities to more easily generate and sell power from their emergency generator engines, and send this power to the electrical grid. Restructuring also allows such facilities to bid a reduction in their electrical demand, and operate emergency generator engines to supplement their grid power purchases. Thus, if the price of electricity is high enough there is an economic incentive for a facility to operate its own emergency generators, and either feed this power into the electrical grid or reduce the facility's demand for power.

Because all facilities within a district simultaneously experience these high electrical prices, the potential is significant for the simultaneous operation of a large number of engine generators, even if such usage is limited to only a few hours per year. If a large number of facilities in a district operate their emergency generators simultaneously, the increase in NOx emissions within the district could be substantial. These increases would occur on the hottest days of the year, which are typically the highest ozone days of the year. Thus, unless the nonemergency operation of emergency generators is restricted, the potential to impact peak ozone concentrations is significant.

To minimize this impact on air quality, the proposed determination restricts the manner in which emergency engines can be used.

7. Other Exemptions

Other exemptions may be justified under certain circumstances, but the inclusion of any additional exemption in a district rule should be fully justified. Before an exemption is added, the district should also investigate whether alternative, less effective controls should be required for a class of engines instead of totally exempting such engines from all control or testing requirements. Factors that should be considered include the need to adopt a RACT or BARCT level of control to meet air quality plan or Health and Safety Code requirements, and cost-effectiveness for a particular engine category.

G. Compliance Dates

In this proposed determination, low fuel consumption engines and diesel engines subject to RACT limits are required to comply with the emissions limits within a year of rule adoption. These engines should be able to meet these limits with relatively minor adjustments or retrofits. For engines required to retrofit more extensive controls or replacement with a different IC engine, an application for a permit to construct must be submitted and deemed complete by the district within one year of rule adoption. Final compliance is required within two years of rule adoption. This time period should be sufficient to evaluate control options, place purchase orders, install equipment, and perform compliance verification testing.

An additional year for final compliance is provided for existing engines that will be permanently removed without being replaced by another IC engine. In many cases, such an operation may be nearing the end of its useful life, and it would not be cost-effective to retrofit the engine with controls for only a year of operation. In addition, over the course of several years, the cumulative emissions from the engine to be removed will be less than if this engine were controlled. Although emissions are higher in the first year, lower emissions occur in all subsequent years.

A district adopting a BARCT level of control should consider modifying the compliance schedule for engines that already meet RACT to provide additional time in certain cases to reduce the financial burden on the engine owner or operator. For example, engines complying with a RACT level of control through the use of a catalyst could be subject to an alternative compliance schedule requiring the BARCT level of control level when the catalyst is next replaced or 3 years, whichever time period is shorter.

H. Inspection and Monitoring Program

It is the engine owner or operator's responsibility to demonstrate that an engine is operated in continuous compliance with all applicable requirements. Each engine subject to control is required to have to have an emission control plan describing how the engine will comply. To reduce the paperwork for engine owners or operators, districts can accept an application to construct as meeting the control plan requirements, as long as the application contains the necessary information.

As part of the emission control plan, an inspection and monitoring plan is required. The inspection and monitoring plan describes procedures and actions taken periodically to verify compliance with the rule between required source tests. These procedures and actions should include the monitoring of automatic combustion controls or operational characteristics to verify that values are within levels demonstrated by source testing to be associated with compliance.

Examples of parameters that can be monitored in an inspection and monitoring program include exhaust gas concentration, air/fuel ratio (air/fuel ratio control signal voltage for catalyst systems), flow rate of the reducing liquid or gas added to the exhaust, exhaust temperature, inlet manifold temperature, and inlet manifold pressure. For engines that are not required to use continuous monitoring equipment, it is recommended that the inspection and monitoring plan require periodic measurement of the measurement of exhaust gas concentrations by a portable NOx monitor.

I. Continuous Monitoring

Continuous monitoring of NOx and O_2 are required for each stationary engine with a brake horsepower rating greater than 1,000 that is permitted to operate more than 2,000 hours per year. This engine size and operating capacity is found in the South Coast AQMD's IC engine rule, and was determined to be cost-effective by the South Coast AQMD. Continuous emissions monitors could be used for this monitoring. As an alternative, if adequate verification is provided, the monitoring of engine parameters and the calculation of concentrations may be used. In either case, these data would be recorded and maintained for at least two years.

J. Source Testing

Source testing of each engine subject to controls would be required after 8,760 hours of engine operation or every 24 months, whichever is the lesser time period. The proposed determination's testing schedule would result in testing nearly every year for IC engines that are operated almost continuously, and testing once every two years for engines operated less than 50 percent of the time.

Typically, source testing of many other controlled sources is required every year. However, for IC engines, source testing can be a significant expense, and allowing a longer period between tests would assure that the cost of source testing would not be out of proportion to other operating expenses. Extended source test periods normally are associated with operating out of compliance for longer periods of time and increased emissions. However, the proposed determination requires the development and implementation of a detailed inspection and monitoring program, which should provide verification that emission controls are operating properly and the IC engine is in compliance between source tests.

K. Records

Records of the hours of operation and type and quantities of fuel consumed each month would also be required for each engine subject to controls or subject to limits on annual hours of operation. These records would be available for inspection at any time, and would be submitted annually to the district.

VIII. COST AND COST-EFFECTIVENESS

The cost of NOx controls for reciprocating IC engines can vary widely, depending on the individual site, size of engine, fuel type, type of engine, operational characteristics of the engine, and other parameters.

For engines requiring the installation or replacement of major pieces of equipment, such as catalysts, engine heads, and turbochargers, the largest expense is the capital cost of controls. The replacement cost for catalysts can also be a major expense.

When an engine is controlled, greater care must be taken to assure the engine is well maintained, and thus maintenance costs increase.

Fuel consumption will be increased by several percent by most of the controls. However, for some uncontrolled engines, modifications that lean the air/fuel ratio may decrease fuel consumption.

Depending on existing equipment and requirements, other costs associated with achieving the determination's requirements may include the purchase and installation of hour and fuel meters; purchase, installation, and operation of emissions monitors; source testing; permit fees; and labor and equipment costs associated with the inspection and monitoring program.

A. Costs and Cost-Effectiveness for RACT

The following four cost-effectiveness tables (Tables 6 through 9) are based on either the average or the range of cost estimates for IC engine controls. These costs are for the retrofit of uncontrolled engines to meet the RACT control limits for high fuel consumption engines. For low fuel consumption engines, the cost of control is expected to be minimal. For the most part, the emission limits for low fuel consumption engines will be met by leaning the air/fuel mixture. The necessary adjustments to lean the air/fuel mixture can be made and checked during regularly scheduled maintenance operations at minimal cost. Some additional instrumentation may also be required to monitor the air/fuel ratio.

Table 6 includes cost-effectiveness estimates developed in 1991 by the Santa Barbara County APCD for engines in their district. The Santa Barbara APCD IC engine rule contains NOx limits similar to the proposed RACT determination limits. The cost of controls and the costs of additional fuel used or fuel saved, source test costs, and annual permit fees were included. These costs are based on the actual average fuel consumption for each horsepower range, which represents capacity factors ranging from about 7 to 60 percent. The cost of catalyst replacement was also taken into account. Capital costs are reflected in the annualized costs.

Table 7 uses the Santa Barbara County APCD operating capacities from Table 6, but uses updated vendor costs for two of the eleven engine/control combinations found in Table 6. These controls are designed to meet the proposed RACT determination limits. Capital costs are based on 1996 equipment costs for several engine makes and models that fit the Santa Barbara County APCD engine size categories. These costs are roughly double the costs from the Santa Barbara County data for rich-burn engines. However, in cases where a turbocharger must be added, the Table 7 costs can exceed the Santa Barbara County APCD data by a factor of up to ten. These differences are almost exclusively due to higher capital costs. On the other hand, for lean-burn engines the costs of a precombustion chamber (clean burn) retrofit from Table 7 are much less than SCR on the same engine size category from Table 6, and are slightly less than electrification, also from Table 6.

Table 8 contains cost and cost-effectiveness estimates from the U.S. EPA's 1993 Alternative Control Techniques (ACT) Document for internal combustion engines. The lean combustion ("Clean Burn") and injection timing retard controls are designed to meet the proposed RACT determination limits. The NSCR control cost range covers both the proposed RACT and BARCT determination limits. The Table 8 cost-effectiveness values are much lower than values for comparable categories in Tables 6 and 7. The primary reason for this is that Table 8 assumes engines operate 8,000 hours per year at full load (i.e., 90 percent of maximum capacity), while the Tables 6 and 7 figures were calculated based on actual capacity factors, which varied from 7 to 64 percent. On the other hand, costs for injection timing retard in Table 8 are much higher than costs found in other information sources. The primary reason for this is that the U.S. EPA assumed electronic controls would have to be retrofitted so that injection timing could be retarded, while the injection timing of most engines can be retarded without this retrofit.

In some applications, stationary engines are used to run compressors which are integral to the engine. In such cases, if the engine is replaced, the associated compressor must also be replaced. If an owner chooses to comply with the proposed determination by replacing the engine, then the cost for replacing the compressor should also be incorporated into the calculation of control equipment costs.

Table 6

Cost-Effectiveness Estimates for IC Engine Controls From Santa Barbara County APCD[1]

Engine/Control	Horsepower Range	Installed Cost ($)	Annualized Cost ($)	Fuel Usage (mmscf/yr)[2]	Cost-Effectiveness ($/ton of NOx Reduced)
Rich-Burn/Prestratified Charge					
	50 - 150	9,185	2,441	4.14	660
	150 - 300	9,185	2,556	4.99	570
	300 - 500	18,335	3,879	2.92	1,500
	500 - 1100	18,260	3,867	4.28	1,000
Rich-Burn/NSCR, single stage					
	50 - 150	7,100	5,062	4.35	1,300
	150 - 300	8,400	5,795	5.24	1,200
	300 - 500	10,600	6,625	3.07	2,400
	500 - 1100	15,000	8,927	4.49	2,200
Rich-Burn/NSCR, two stage					
	50 - 150	13,500	8,178	4.35	2,100
	150 - 300	15,300	9,155	5.24	1,900
	300 - 500	19,700	11,057	3.07	4,000
	500 - 1100	28,500	16,302	4.49	4,000
Rich-Burn/Electrification, no power line[3]					
	50 - 150	15,600	6,883	4.14	1,700
	150 - 300	19,500	8,409	4.99	1,700
	300 - 500	25,000	7,072	2.92	2,400
	500 - 1100	60,800	14,198	4.28	3,300

(continued)

1 Reference: "Staff Report - Proposed Rule 333 - Control of Emissions from Reciprocating Internal Combustion Engines," December, 1991, Santa Barbara County APCD.

2 Average natural gas used for each category in millions of standard cubic feet per year

3 "Electrification, no power line" assumes that electrical grid power is next to the electric motor, so a power line is not required.

Table 6 (continued)

Cost-Effectiveness Estimates for IC Engine Controls From Santa Barbara County APCD[1]

Engine/Control	Horsepower Range	Installed Cost ($)	Annualized Cost ($)	Fuel Usage (mmscf/yr)[2]	Cost-Effectiveness ($/ton of NOx Reduced)
Rich-Burn/Electrification, 1,027 feet of power line[3]					
	50 - 150	25,920	8,518	4.14	2,100
	150 - 300	29,820	10,045	4.99	2,000
	300 - 500	34,320	9,550	2.92	3,300
	500 -1100	71,120	15,834	4.28	3,700
Lean-Burn/SCR					
	150 - 300	153,500	37,591	3.51	13,000
	300 - 500	154,000	40,944	2.62	20,000
	500 - 1,100	155,000	52,330	14.44	4,500
Lean-Burn/Clean Burn Retrofit					
	500 - 1,100	516,870	80,775	13.61	7,400
Lean-Burn/New Clean Burn Engine					
	500 - 1,100	214,000	32,024	13.32	3,000

(continued)

1 Reference: "Staff Report - Proposed Rule 333 - Control of Emissions from Reciprocating Internal Combustion Engines," December, 1991, Santa Barbara County APCD.

2 Average natural gas used for each category in millions of standard cubic feet per year

3 "Electrification, 1,027 feet of power line" assumes that this length of power line will have to be built to connect the electric motor to the electric grid.

Table 6 (continued)

Cost-Effectiveness Estimates for IC Engine Controls From Santa Barbara County APCD[1]

Engine/Control	Horsepower Range	Installed Cost ($)	Annualized Cost ($)	Fuel Usage (mmscf/yr)[2]	Cost-Effectiveness ($/ton of NOx Reduced)
Lean-Burn/Electrification, no power line[3]					
	150 - 300	19,500	6,724	3.41	2,000
	300 - 500	25,000	6,670	2.54	2,600
	500 - 1,100	60,800	24,576	14.02	1,800
Lean-Burn/Electrification, 1,027 feet of power line[4]					
	150 - 300	29,820	8,359	3.41	2,500
	300 - 500	34,320	8,306	2.54	3,300
	500 - 1,100	71,120	26,213	14.02	1,900
Lean-Burn/Electrification of compressor[5]					
	500 - 1,100	390,000	74,392	7.04	13,000

1 Reference: "Staff Report - Proposed Rule 333 - Control of Emissions from Reciprocating Internal Combustion Engines," December, 1991, Santa Barbara County APCD.

2 Average natural gas used for each category in millions of standard cubic feet per year.

3 "Electrification, no power line" assumes that electrical grid power is next to the electric motor, so a power line is not required.

4 Electrification, 1,027 feet of power line assumes that this length of power line will have to be built to hook the electric motor to the electric grid.

5 Includes replacement of compressor.

Table 7

Cost-Effectiveness Estimates for IC Engine Controls
Based on 1996 Vendor Prices and Santa Barbara County APCD Data[1]

Engine Type	Control Type	Horsepower Range	Cost-Effectiveness in Dollars per Ton of NOx Removed
Rich-Burn	Prestratified Charge	300 - 500	1,800 - 4,000[2]
		500-1,100	1,500 - 8,300[2]
Lean-Burn	Clean Burn Retrofit	300 - 500	1,300 - 2,000

[1] Reference: Personal Communication, Bo Mikkelsen, Emissions Plus Inc., January 12, 1996, and "Staff Report - Proposed Rule 333 - Control of Emissions from Reciprocating Internal Combustion Engines," December, 1991, Santa Barbara County APCD.

[2] Higher values reflect the costs for converting a naturally aspirated engine to turbocharged/aftercooled version, to maintain original power rating.

Table 8

Cost-Effectiveness Estimates for IC Engine NOx Controls From U.S. EPA ACT Document for IC Engines[1]

Engine/Control	Horsepower	Total Capital Costs (10^3 \$)	Total Annual Costs[2] (10^3 \$)	Cost-Effectiveness (\$/ton)
Rich-Burn/Prestratified Charge without Turbocharger				
	80-500	20-50	70-80	1,300-7,200
	501-1,000	50-55	80-83	750-1,300
	1,001-2,500[3]	55-62	83-91	300-750
Rich-Burn/Prestratified Charge with Turbocharger				
	80-500	28-112	72-94	1,500-7,400
	501-1,000	112-133	94-101	900-1,500
	1,001-2,500[3]	133-151	101-112	370-900
Rich-Burn/NSCR				
	80-500	15-27	69-79	1,260-6,900
	501-1,000	27-41	79-90	750-1,260
	1001-2,500[3]	41-87	90-124	395-750
Rich-Burn/Conversion to Low Emissions Lean-Burn ("Clean-Burn")				
	80-500	39-116	12-23	480-1,200
	501-1,000	116-207	23-50	420-480
	1,001-2,500[3]	207-482	50-114	375-420

(continued)

1 Reference: "Alternative Control Techniques Document -- NOx Emissions from Stationary Reciprocating Internal Combustion Engines," U.S. EPA, July, 1993.

2 Assumes operation at maximum rated horsepower for 8,000 hours per year.

3 Largest known rich-burn stationary engine is 1,978 horsepower.

Table 8 (continued)

Cost-Effectiveness Estimates for IC Engine NOx Controls
From U.S. EPA ACT Document for IC Engines[1]

Engine/Control	Horsepower	Total Capital Costs (10^3 $)	Total Annual Costs[2] (10^3 $)	Cost-Effectiveness ($/ton)
Lean-Burn/Conversion to Low Emissions Lean-Burn ("Clean-Burn")				
	200-500	61-116	15-27	410-590
	501 - 1,000	116-207	27-45	350-410
	1,001-2,500	207-482	45-102	310-350
	2,501-4,000	482-756	102-158	300-310
Lean Burn/SCR				
	200-500	324-346	180-196	2,900-6,800
	501-1,000	346-382	196-220	1,700-2,900
	1,001-2,500	382-491	220-295	890-1,700
	2,501-4,000	491-600	295-370	700-890
Diesel/Injection Timing Retard				
	80-500	12	6.2-10	770-2,900
	501-1,000	12-16	10-16	590-770
	1,001-2,500	16-24	16-32	450-590
	2,501-4,000	24	32-46	440-450

(continued)

1 Reference: "Alternative Control Techniques Document -- NOx Emission from Stationary Reciprocating Internal Combustion Engines," U.S. EPA, July, 1993.

2 Assumes operation at maximum rated horsepower for 8,000 hours per year.

Table 8 (continued)

Cost-Effectiveness Estimates for IC Engine NOx Controls From U.S. EPA ACT Document for IC Engines[1]

Engine/Control	Horsepower	Total Capital Costs (10^3 $)	Total Annual Costs[2] (10^3 $)	Cost-Effectiveness ($/ton)
Dual Fuel Engines/Injection Timing Retard				
	700-1,000	12-16	10-13	900-990
	1,001-2,500	16-24	13-25	680-900
	2,501-4,000	24	25-35	600-680
Dual Fuel Engines/Conversion to Low Emissions Lean-Burn ("Clean-Burn")				
	700-1,000	720-855	182-216	3,800-4,600
	1,001-2,500	855-1,530	216-390	2,700-3,800
	2,501-4,000	1,530-2,200	390-563	2,500-2,700

1 Reference: "Alternative Control Techniques Document -- NOx Emission from Stationary Reciprocating Internal Combustion Engines," U.S. EPA, July, 1993.

2 Assumes operation at maximum rated horsepower for 8,000 hours per year.

Costs and cost-effectiveness data are also available from the San Luis Obispo County APCD's Staff Report for Rule 431, Stationary Internal Combustion Engines. Table 9 summarizes the range of these costs for the retrofit of 15 rich-burn engines with NSCR.

Table 9

San Luis Obispo Costs and Cost-Effectiveness Estimates for RACT Controls On Rich-Burn IC Engines

Engine Size (BHP)	NOx Reductions (Tons/yr)	Total Annual Cost ($)	Cost-Effectiveness ($/ton)
85-575	1.1-49.6	9,600-17,300	350-9,400

Reference: San Luis Obispo County Air Pollution Control District Staff Report, Rule 431, Stationary Combustion Engines, November 13, 1996.

B. Costs and Cost-Effectiveness for BARCT

Tables 10 and 11 summarize the cost and cost-effectiveness for controlling uncontrolled high fuel consumption diesel engines to an emissions level representative of BARCT. For high fuel consumption spark-ignited engines, the same or similar controls can be used to achieve both the RACT and BARCT emission limits. For example, if catalysts are used, compared to RACT a catalyst designed to meet the BARCT limit may be larger, have a higher concentration of active catalyst materials, may include a more sophisticated air/fuel ratio controller, and may need a more effective inspection and maintenance program. All of these differences tend to increase the cost of BARCT controls in comparison to RACT controls. However, when similar controls are used, the incremental increase in costs for BARCT controls in comparison to RACT controls is generally minor.

The cost-effectiveness in dollars per ton figures are substantially greater for diesel engines with 8 and 11 percent capacity factors, and are much lower for engines with higher capacity factors. For this reason, the BARCT determination includes two NOx limits: one applicable to low fuel consumption engines (i.e., low capacity factor) and a more effective limit for high fuel consumption engines (i.e., high capacity factor). For high fuel consumption diesel engines, selective catalytic control (SCR) is generally cost-effective and can meet the more effective NOx limits.

Table 10

Cost and Cost-Effectiveness for SCR NOx Control of Diesel Engines in Ventura County[1]

Size Range (BHP)	Reduction Needed (%)[2]	Capital Cost ($)	O&M Costs ($/year)[3]	Capacity Factor (%)	Cost-Effectiveness ($/ton)
450	86	86,500-277,500	10,000	11	13,000-27,000
465	84	86,500-277,500	10,000	17	2,000-4,000
650	81	105,000-346,500	15,000	8	14,000-28,000
800	91	105,000-346,500	40,000	52	1,000-1,500
1200-1440	86	105,000-346,500	40,000	52	640-1,000

1 Reference: Ventura County APCD Staff Report for Rule 74.9, December 1993.
2 Average reduction needed to meet an 80 ppm NOx limit
3 O&M = operation and maintenance

Table 11

BARCT Cost-Effectiveness Estimates for IC Engine Controls From U.S. EPA ACT Document for IC Engines[1]

Engine/Control	Horsepower	Total Capital Costs (10^3 $)	Total Annual Costs[2] (10^3 $)	Cost-Effectiveness ($/ton)
Diesel/SCR				
	80-500	195-236	145-165	3,500-19,000
	501-1,000	236-285	165-184	2,000-3,500
	1,001-2,500	285-431	184-261	1,100-2,000
	2,501-4,000	431-577	261-332	880-1,100
Dual Fuel Engines/SCR				
	700-1,000	255-284	170-183	2,700-3,600
	1,001-2,500	284-431	183-247	1,500-2,700
	2,501-4,000	431-577	247-310	1,200-1,500

[1] Reference: "Alternative Control Techniques Document -- NOx Emission from Stationary Reciprocating Internal Combustion Engines," U.S. EPA, July 1993.

[2] Assumes operation at maximum rated horsepower for 8,000 hours per year.

Another source of information on BARCT NOx control costs for IC engines is the South Coast AQMD. In 1995, Rule 1110.2 was modified, and data on costs of control equipment from the 1990 Staff Report were updated to 1995 dollars. The cost-effectiveness of NSCR was estimated to be $4,800 per ton of NOx reduced, while the cost-effectiveness of SCR was estimated to be $9,500 per ton of NOx reduced. The costs and NOx reductions from the use of cyanuric acid were estimated to be about the same as SCR.

C. Other Costs

The previous tables, for the most part, have covered the capital, operating, and maintenance costs for controls. Other expenses may also be encountered to comply with the proposed determination. In the case of hour meters and fuel meters, many engines already have such measuring devices, so there would be no additional cost. For engines using SCR, often the cost of a continuous NOx monitor is included in the cost of controls. Some of the cost-effectiveness estimates already presented included the cost of source tests. For completeness, the following information on these costs is provided.

This proposed determination requires the use of an hour meter on exempt emergency standby engines operating fewer than 100 hours per year. In addition, many districts will likely require the use of fuel and hour meters for recordkeeping and compliance verification purposes. Hour meters typically cost between $120 and $200 each, while a fuel meter package for a diesel engine with an accuracy within one percent costs about $1,300.

This proposed determination also requires the installation of an emissions monitoring system for engines rated 1,000 brake horsepower and greater and permitted to operate more than 2,000 hours per year. Costs of such a system vary depending on whether continuous emissions monitors are used or parametric monitoring is employed. Cost of a continuous emissions monitor is about $75,000. The installed cost of a parametric system is about $75,000 for the first engine, and $34,000 for each subsequent similar engine at a facility. For a facility consisting of five identical engines, annual maintenance costs are estimated as $10,000 to $15,000 ($2,000 to $3,000 per engine) for a parametric system, and up to $100,000 to $150,000 ($20,000 to $30,000 per engine) for a continuous emissions monitor system.

The cost of a reference method source test is about $3,000 per engine. Costs are less if multiple engines are tested at the same time.

As part of the inspection and maintenance requirements, it is recommended that exhaust emissions be periodically checked with a hand-held portable analyzer. The cost of a hand-held portable analyzer is about $10,000 to $15,000. Many engine operators who perform their own maintenance and maintain several engines already have such an analyzer. Smaller operators generally contract out engine maintenance, and nearly all maintenance contractors already have analyzers. Thus, in most cases, requiring periodic checks with an analyzer is not expected to increase costs significantly.

D. Incremental Costs and Cost-Effectiveness

New requirements for the adoption of rules and regulations were passed by the State Legislature in 1995. These requirements, found in Health and Safety Code Section 40920.6, apply to districts when adopting BARCT rules or feasible measures. Specifically, when adopting such rules, districts must perform an incremental cost-effectiveness analysis among the various control options. Incremental cost-effectiveness data represents the added cost to achieve an incremental emission reduction between two control options. Districts are allowed to consider incremental cost-effectiveness in the rule adoption process.

Districts that adopt a BARCT level of control for IC engines may have already required a RACT level of control for these engines. Table 12 provides incremental cost-effectiveness estimates for the case where a RACT level of control has already been installed (i.e., baseline is RACT), and the control equipment is either modified or replaced to meet BARCT limits.

Table 12

Cost and Cost-Effectiveness Summary for Application of BARCT To RACT Controlled Engines[1]

Control Technology	Size Range (HP)	Number of Engines	Reduction Needed (%)	Emissions Reduction (tons/yr)[2]	Capital Costs ($)	O&M Costs ($/yr)	Cost-Effectiveness ($/ton)[3]
Rich-burn							
From NSCR to improved NSCR							
	100-200	6	36	2.93	9,185	1,888	9,300
	225	1	22	0.37	9,185	1,888	8,200
	412	2	25	0.79	18,335	1,673	10,000
	625	1	19	0.79	18,260	2,399	6,000
	700-800	3	50	6.27	18,260	2,399	2,300
	1250	3	34	5.85	18,260	2,399	3,300
From PSC to NSCR							
	300	3	50	7.84	10,600	1,673	1,300
	330	3	53	0.62	10,600	1,673	17,000[4]
Lean-burn							
From SCR to improved SCR							
	660	2	62	14.81	105,000-346,500	15,000	3,800-7,900
From Clean Burn to added SCR							
	1108	8	29	39.38	105,000-346,500	15,000	6,300-13,000
Diesel							
From SCR to improved SCR							
	503	1	34	0.64	50,000-105,000	250	10,000-21,000
	4500	1	35	8.04	50,000-105,000	250	810-1,700

1. Reference: Ventura County APCD Staff Report for Rule 74.9, December 1993
2. Based on actual capacity factor
3. Capital recovery factor of .125 used (approximately 9 percent interest for 15 years)
4. Operator proposed electrification for these engines

When performing incremental cost-effectiveness analyses, in some cases an uncontrolled baseline may be appropriate. Table 13 summarizes an incremental cost-effectiveness comparison for an uncontrolled baseline. For example, the costs for controlling an uncontrolled engine with the application of prestratified charge controls is estimated, along with the costs for replacing the engine with an electric motor. Emission reductions for application of these two different control methods to an uncontrolled engine are also estimated. The incremental cost-effectiveness is determined by dividing the difference in costs by the difference in emission reductions. The Table 13 estimates were developed from data found in Tables 6 and 7. These data were sufficient only to compare proposed RACT levels to electrification. For rich-burn engines, it was assumed that both the prestratified charge and NSCR control technologies would achieve a NOx reduction performance of 50 ppm or 90 percent control. The least expensive of these two technologies (prestratified charge) was used to compare against electrification. The emissions reduction associated with electrification was assumed to be 100 percent. For lean-burn engines, the only control less expensive than electrification was clean burn retrofit. An incremental cost-effectiveness comparison between clean burn and electrification is included in Table 13.

Table 13

Incremental Cost-Effectiveness Estimates for IC Engine Controls[1]

Engine Type	Control Comparison	Horsepower	Incremental Cost-Effectiveness in Dollars per Ton Of NOx Removed
Rich-Burn	From Prestratified Charge to Electrification	50-150	11,000-15,000
		150-300	12,000-15,000
		300-500	11,000-19,000
		500-1,100	24,000-28,000
Lean-Burn	From Clean Burn Retrofit to Electrification	300-500	5,000-11,000

[1] Reference: "Staff Report - Proposed Rule 333 - Control of Emissions from Reciprocating Internal Combustion Engines," December 1991, Santa Barbara County APCD.

Another incremental cost-effectiveness study has been performed by the San Diego County APCD. The costs and cost-effectiveness of installing NSCR on three rich-burn engines was calculated for 90 and 95 percent NOx control. The incremental costs for increasing the effectiveness from 90 percent to 95 percent were also calculated. Continuous operation of the engines (8,760 hours per year) was assumed. Table 14 summarizes the emissions and costs for all three engines combined.

Table 14

Incremental Cost-Effectiveness Between 90% and 95% NOx Control For Application of NSCR on Three Rich-Burn Engines[1]

Incremental NOx Reduction (tons/yr)	Incremental Capital Costs ($)	Incremental Annualized Costs ($)	Incremental Cost-Effectiveness ($/ton NOx reduced)
9	10,000	12,500	1,380

1 Source: "Children's Hospital Cost-Effectiveness for NSCR," Godfrey Aghoi, San Diego County APCD, June 14, 1996.

Incremental cost-effectiveness values should be used to determine if the added cost for a more effective control option is reasonable when compared to the additional emission reductions that would be achieved by the more effective control option. Historically, when determining cost-effectiveness, districts have estimated the costs and emissions reductions associated with controlling uncontrolled sources. This latter method is sometimes called "absolute" cost-effectiveness. Incremental cost-effectiveness should not be compared directly to a cost-effectiveness threshold that was developed for absolute cost-effectiveness analysis. Incremental cost-effectiveness calculations, by design, yield values that can be significantly greater than the values from absolute cost-effectiveness calculations. Direct comparisons may make the cost-effectiveness of an economic and effective alternative seem exceedingly expensive.

IX. RULE EFFECTIVENESS

Rule effectiveness is a measure of the actual emission reductions achieved by a rule. Very few data are available on rule effectiveness are available for stationary internal combustion engines. However, one study ("Phase III Rule Effectiveness Study, VCAPCD Rule 79.4, Stationary Internal Combustion Engines," October 1, 1994) has been conducted.

This study covered 33 engines at 15 facilities. The ARB performed unannounced source tests on 22 engines for the study, while the Ventura County District witnessed or reviewed an additional 11 annual source tests. Five of the 22 engines tested by the ARB were found in violation, while one of the 11 engines for which annual source tests were performed was found in violation. The engines that were found in violation exceeded the rule's limits by 26 to 1,551 percent. Average emissions from the 33 engines were found to be 32 percent greater than the rule limits. For the 27 engines in compliance, emissions were well below the rule's limits.

The frequency of non-compliance was greater for unannounced source tests than for annual or announced source tests (5 of 22 compared to 1 in 11). One of the main reasons for this difference is that, based on interviews with the engine owners or operators, in most cases portable emission analyzers are used to tune engines for better emissions performance immediately before announced source tests are performed.

Data from the study indicate that many of the problems with compliance involve maintaining the proper air/fuel ratio. The use of automatic electronic air/fuel ratio controllers on NSCR systems appears to greatly reduce such problems.

One of the conclusions of the study was that most non-compliant engines can come into compliance easily and quickly with minor adjustments. It also appears that compliance can be significantly improved if more frequent inspections are performed. During the time period when the study was conducted, the District's rule required quarterly inspections with portable analyzers and an annual source test. To improve rule effectiveness, the rule was revised to change the frequency of inspections with portable analyzers from quarterly to monthly, while the announced source test frequency was decreased from once a year to once every two years.

Based on the results of the Rule Effectiveness Study, we recommend in the proposed determination that all controlled engines be subject to an inspection and monitoring plan. Where feasible, this plan should include monthly testing with portable analyzers.

The study also found that engine operators often did not adjust engines to optimal settings except for announced source tests and quarterly inspections. We recommend that, during an initial source test, optimal settings are determined for engine operating parameters affecting emissions. The inspection an maintenance program should require that these optimal settings be frequently checked and maintained. In this fashion, emissions reductions should be maximized.

Although the effectiveness of this proposed determination cannot be quantified, it should be more effective than the Ventura County study results. The proposed determination recommends monthly, rather than quarterly, testing by portable analyzers. The proposed determination also includes other, more effective provisions such as: the identification of optimal values for parameters important to emissions control; the frequent checking, reporting, and recordkeeping for these parameters; and mandatory corrective action if any parameter is not within the acceptable range. Examples of parameters that may require monitoring include air/fuel ratio, exhaust temperature, inlet manifold temperature, and inlet manifold pressure.

X. IMPACTS

A. Air Quality

Oxides of nitrogen (NOx) is an air quality concern for several reasons. NOx is a precursor to ozone, and State and federal ozone ambient air quality standards are violated throughout many parts of California. In addition, although most NOx is emitted in the form of nitric oxide (NO), on most days NO will rapidly oxidize to form nitrogen dioxide (NO_2). There are state and federal ambient air quality standards for NO_2. NOx is also a precursor to particulate nitrate, which can contribute to violations of PM10 (particulate matter less than 10 micrometers in aerodynamic diameter) and PM2.5 ambient air quality standards. Violations of PM10 standards are even more widespread than ozone violations in California. Reductions in NOx emissions will reduce ozone, nitrogen dioxide, and PM10 and PM2.5 concentrations, and reduce the number of violations of ambient air quality standards for these four pollutants.

Table 15 lists emission reduction estimates by district from the adoption of a rule to control NOx emissions from stationary IC engines. The districts listed are limited to those that are nonattainment for the State ozone standard, and either do not have an IC engine rule or have an IC engine rule that is significantly less effective than the proposed determination. In some cases, such as the Bay Area, a district's existing rule is less effective than the proposed determination, but emission reductions from adoption of a BARCT level of control cannot be quantified.

The Table 15 emission reduction estimates were calculated assuming no reduction would come from engines emitting one ton or less of NOx per year. Engines with emissions of one ton or less are often standby emergency generators which would be exempt from control requirements. In addition, no reductions were assumed for engines that are already controlled, based on the emission factors from the emissions inventory. No reductions were also assumed for engines described as operating mobile equipment.

Fuel consumption was not surveyed, so it is unclear how many engines may be subject to the low fuel consumption limits rather than the high fuel consumption limits. In addition, some districts may adopt a RACT level of control, while others may need to adopt a BARCT level of control. For these reasons, the Table 15 emission reduction estimates assume NOx will be reduced by 30 percent for diesel engines and 90 percent for natural gas fueled engines. These levels represent RACT for diesel engines, and BARCT for low fuel consumption diesel engines. These levels also represent RACT for rich-burn engines, and BARCT for lean-burn engines.

It should be noted that the emission reductions estimated in Table 15 are based on the 1994 inventory. Since in some respects this inventory may underestimate actual emissions (see Chapter I), the actual emission reductions may be greater than the estimates in Table 15. However, to the extent that engines have already been controlled but are reported in the inventory as being uncontrolled, the Table 15 estimates may be higher than actual.

Table 15

Estimated NOx Emission Reductions for Stationary Source IC Engines[1]

Emissions in Tons per Year

District	1994 Inventory	Controlled	Reduction
Butte County AQMD	14	7	7
Colusa County APCD	710	71	639
Feather River AQMD	359	36	323
Glenn County APCD	28	20	8
Imperial County APCD	1,225	1,171	54
Monterey Bay Unified APCD	145	130	15
Placer County APCD	3	0	3
Yolo-Solano AQMD	33	33	0

[1] Reference: ARB 1994 Emissions Inventory

B. Economic

The economic impacts from meeting the requirements of this proposed determination will be a function of the type of engine and controls used, and the economic health of the engine owner or operator. The costs and cost effectiveness are discussed in detail in Chapter VIII.

Looking at typical costs for a typical engine, most of the engines affected by an IC engine rule will be rich-burn, and an NSCR catalyst is the control method expected to be used on most of these rich-burn engines. The total (annualized capital plus operating, replacement, fuel, and maintenance) cost of an NSCR catalyst will increase total engine operating costs by about 10 percent. The required source testing would add to this total. For example, the total cost of operating a 500 horsepower rich burn engine/generator for one year at 50 percent of capacity would be about $150,000, and the corresponding cost for a catalyst would be about $15,000.

Source testing would cost about $3000 per test for a single engine, and less if multiple engines are tested at the same time.

The costs of retrofitting a lean-burn engine to meet the proposed determination's NOx limits will generally be greater than for a rich-burn engine. However, owners and operators of lean burn engines tend to be larger, better financed businesses that can more easily absorb greater costs. Retrofit costs can vary significantly, with lower costs associated with the use of an economical clean burn retrofit kit, and higher costs if a turbocharger or other expensive equipment must be replaced or added, or if SCR controls are used.

For larger engines operating a substantial number of hours per year, NOx and oxygen concentrations must be monitored continuously. In addition, for other engines using SCR, a continuous NOx monitor is often included as part of the controls package. The cost of continuous monitoring can be significant. The purchase and installation costs of a stand alone NOx monitor is about $75,000. As an alternative to monitoring NOx directly, districts may find parametric monitoring to be a reasonable alternative. In parametric monitoring, several engine parameters are monitored, and these valued are used to calculate NOx emissions. The monitoring of engine parameters is generally less expensive than monitoring NOx directly. The capital cost for a parametric system is about $75,000 for the first engine at a site, and $34,000 for each similar engine at the site. For a facility consisting of five identical engines, annual maintenance costs for a continuous monitoring system can be as high as $100,000 ($20,000 to $30,000 per engine), while for a parametric system annual maintenance costs are about $10,000 to $15,000 ($2,000 to $3,000 per engine).

C. Catalysts

Both NSCR and SCR catalysts contain heavy metals and other toxic substances that may create environmental problems if they are not disposed of properly. In the case of NSCR catalysts, it is usually cost-effective to reclaim and recycle the heavy metals from spent catalysts. For all catalysts, the cost of proper disposal is relatively minor, and catalyst vendors generally will agree to dispose of their own used catalysts at no charge.

In the case of SCR, ammonia is injected into the exhaust gas to reduce NOx, and some of the ammonia is released into the atmosphere unreacted. Ammonia is a toxic compound at high concentrations. At lower concentrations, ammonia can cause health effects and can be a nuisance due to odor. Therefore, many districts have adopted rules or permits which limit the ammonia concentration in the exhaust vented to the atmosphere. These limits vary from a few ppmv to about 50 ppmv. If the exhaust contains no more than this concentration range, the ground level concentration of ammonia should be well below the level at which any known health effects occur.

There are also safety concerns associated with accidental spills of ammonia. Not only is ammonia a toxic compound, but it is also a fire hazard at extremely high concentrations. These concerns can be mitigated by constructing and operating the ammonia system in conformance with existing safety and fire regulations. Safety can also be greatly enhanced if aqueous, rather than anhydrous, ammonia is used. With aqueous ammonia, the ammonia tends to stay bound to water rather than escape as a gas into the atmosphere, and thus both the health effects and explosive danger from accidental ammonia spills can be minimized. Because water becomes saturated at about 25 percent ammonia by weight, aqueous ammonia tanks must be about four times larger than if anhydrous ammonia were used. Consequently, the cost of storage tanks and transportation costs for aqueous ammonia will be greater than if anhydrous ammonia were used.

D. Methanol

Methanol is a toxic compound that can cause serious health effects if ingested, breathed, or absorbed through the skin. In addition, combustion of methanol in IC engines can result in elevated formaldehyde exhaust emissions. The ARB has identified formaldehyde as a toxic air contaminant. Careful handling of methanol and conformance to existing health and industrial standards should minimize any safety hazards associated with methanol. Formaldehyde emissions can be minimized by assuring that the IC engine does not operate overly rich, and by the use of an oxidation catalyst. Methanol has been used as a fuel for cars and buses for a number of years with little or no adverse health impacts noted.

E. Water Usage

Very few engines are expected to use water for NOx control. For engines that use water, the consumption of water is not expected to be significant. For diesel engines, assuming a water/fuel ration of 0.5 pounds of water per pound of diesel fuel and operation at 50 percent of capacity, water usage will be about two gallons per hour or 20,000 gallons per year for a 200 horsepower engine. For a 2,000 horsepower engine operated at 50 percent capacity, water usage will be about 20 gallons per hour or 200,000 gallons per year.

F. Energy Impacts

Controls used to meet the NOx limits in this proposed determination are not expected to have a significant impact on energy usage. In many instances, controls may increase fuel consumption by a few percent, but there may be a net fuel savings in other instances. For example, if a NOx limit is met by replacing a rich-burn engine with a new, low NOx lean-burn engine, fuel consumption will decrease by about five to eight percent.

XI. OTHER ISSUES

A. Effect of ARB and U.S. EPA Regulations

The districts in California have primary jurisdiction over stationary sources. Thus, districts have the authority to adopt rules and regulations controlling emissions from IC engines that are stationary sources. The United States Environmental Protection Agency (U.S. EPA) has statutory authority to control emissions from engines that are not stationary sources, such as motor vehicles. In many cases, this authority is delegated to the State of California (ARB). In addition, several sections of the Health and Safety Code either allow or require the ARB to control nonvehicular engines.

1. ARB IC Engine Regulations

There are two major provisions in State law allowing or requiring the ARB to control nonvehicular IC engines. The first of these, Section 43013 of the Health and Safety Code, grants the ARB authority to adopt standards and regulations for a wide variety of nonvehicular engines. These include off-highway motorcycles, off-highway vehicles, construction equipment, farm equipment, utility engines, locomotives, and marine vessels. Regulations have been adopted for several engine categories under Section 43013. Some of these engines could be used in applications where the engines are considered to be stationary sources. In such situations, the ARB has determined that it holds concurrent jurisdiction with the districts, and the engine must meet both the ARB and district rules and regulations. The ARB requirements do not conflict with or constrain district jurisdiction over stationary source engines.

The second major provision in State law regarding ARB jurisdiction over nonvehicular IC engines can be found in Health and Safety Code Sections 41750 through 41755. These sections require the ARB to develop uniform statewide regulations for the registration and control of portable engines. Regulations were adopted March 27, 1997, and became effective September 17, 1997.

In districts that have never regulated portable engines, an engine owner or operator may choose comply with the ARB registration and control program, but such compliance is not mandatory. In districts that regulate portable engines, the engine owner or operator must comply with either the district regulations or the ARB program. If a district has the authority to regulate portable engines and has regulated them in the past, but has since rescinded these regulations, compliance with the ARB program is mandatory.

By complying with the ARB program, the owner or operator of a portable engine becomes exempt from all district regulations. To conform to State law, this proposed determination exempts engines that have registered under requirements adopted by the ARB on March 27, 1997. These requirements can be found in Sections 2450 through 2465, Article 5, Title 13, California Code of Regulations.

A potential conflict exists between State and federal requirements for portable equipment used at a major stationary source. The U.S. EPA requires districts to issue federal Title V permits to sources that are considered major stationary sources by the U.S. EPA. Currently, it is the U.S. EPA's policy to include all portable equipment in Title V permits. This inclusion constitutes regulation of portable equipment by the district. In an attempt to resolve this conflict, Title V permit holders are prohibited from registering portable equipment under the State program. The ARB is working with the U.S. EPA to assure that this conflict is resolved.

2. U.S. EPA IC Engine Regulations

A district's ability to control stationary IC engines may be affected by federal regulations for nonroad engines. Effective July 18, 1994, the U.S. EPA adopted 40 CFR Part 89-- Control of Emissions from New and In-use Nonroad Engines. As part of this rulemaking, a definition of nonroad equipment was adopted which distinguishes between stationary and nonroad sources. Nonroad engines are engines not used for self propulsion of motor vehicles and not permanently attached to a foundation. However, if such an engine operates at one location for more than 12 months (or, for a seasonal source, the duration of the season), it is considered a stationary source. On the other hand, if the engine moves within 12 months (or, for a seasonal source, during the season), even if the move is within the boundary of the same stationary source, the engine may be considered to be a nonroad engine. 40 CFR Part 89 should be consulted for a more detailed explanation of the definition of nonroad engine

Although under U.S. EPA definitions a nonroad engine cannot be a stationary source, some districts have definitions that differ from the U.S. EPA definitions, and may consider a nonroad engine to be a stationary source in certain circumstances.

This overlap in stationary source and nonroad engine is important, since section 209 (e) (1) of the federal Clean Air Act amendments of 1990 preempts states and local agencies from adopting or attempting to enforce standards or other requirements for new nonroad engines smaller than 175 horsepower used either in construction or farming. Section 209 (e) (2) allows delegation to California the control of most other nonroad engines.

Under the delegation provisions, the ARB has adopted emission limits for some categories of nonroad engines, and will continue to request delegation and adopt emission standards for other categories of nonroad engines. ARB's interpretation of the federal Clean Air Act Amendments of 1990 is that the U.S. EPA preempts districts from requiring controls on all new nonroad engines. However, districts can still permit and register these engines, and can regulate their operation (e.g., place limits on fuel consumption or hours of operation).

According to the U.S. EPA, nonroad engines built prior to a date to be specified shall not be considered new. This date is expected to be November 15, 1990. In addition, at some point in the life of a new nonroad engine, it will no longer be considered new and the preemption provisions will no longer hold. Provisions found in 40 CFR Part 89 indicate a new nonroad engine is no longer considered new after it has been sold to the ultimate user (i.e., a party who will operate the engine) or has been placed into operation. However, if a state or local agency were to require the retrofit of controls on engines that have just been sold to the ultimate user or just placed into operation, this would be considered circumvention of the preemption provisions and would not be allowed by the U.S. EPA. On the other hand, at some point in the new engine's life, the engine is no longer new, and states and local agencies can require further controls. The U.S. EPA has yet to clearly define when states and districts can require further controls.

Some of the provisions in the U.S. EPA nonroad engine regulations have created controversy, and industry has challenged these provisions in court. Depending on how these issues are resolved, the U.S. EPA may have to change or clarify some of the above described nonroad engine provisions.

Due to the U.S. EPA preemption provisions, the proposed determination exempts from rule requirements engines that meet the U.S. EPA definition for new nonroad engines.

B. Emissions of Hazardous Air Pollutants/Toxic Air Contaminants by IC Engines

1. Hazardous Air Pollutants/Toxic Air Contaminants Emitted

Fuels used in stationary IC engines and exhaust gases from these engines contain toxic substances. These substances are labeled hazardous air pollutants (HAPs) by the U.S. EPA and toxic air contaminants (TACs) by the ARB. A TAC is defined in the Health and Safety Code as an air pollutant which may cause or contribute to an increase in mortality or in serious illness, or which may pose a present or potential hazard to human health. In April 1993, the ARB identified all HAPs listed in subsection (b) of Section 112 of the federal Clean Air Act as TACs. Toxic substances differ from traditional pollutants such as NOx, CO, SOx, and particulate matter because there are a large number of substances that are potentially toxic and there is often no identified threshold or safe levels for many toxics. In addition, toxic substances tend to be emitted in much lower amounts than traditional pollutants, but their toxicity tends to be much greater.

Emissions of toxic substances from the exhaust of natural gas-fired engines are the result of incomplete combustion. These toxic substances include: propylene, formaldehyde, polycyclic aromatic hydrocarbons (PAHs), acetaldehyde, acrolein, benzene, ethyl benzene, toluene, and xylenes. The toxic substances having the highest mass emissions are generally formaldehyde, propylene, and benzene.

Emissions of toxic substances from the exhaust of diesel-fired engines are also the result of incomplete combustion. These toxic substances include: propylene, formaldehyde, PAHs, acetaldehyde, acrolein, benzene, xylenes, toluene, and naphthalene.

In addition, data exist indicating the exhaust from diesel engines is a potential carcinogen. Diesel exhaust is composed of the toxic substances listed previously and fine particulate matter, and the interaction of these components is of concern. Diesel exhaust is listed as a substance subject to Proposition 65 notification requirements. Diesel exhaust is currently under evaluation by the ARB for listing as a TAC.

2. U.S. EPA Requirements

The U.S. EPA regulation of HAPs is authorized in Section 112 of the federal Clean Air Act. Specifically, Section 112(d) requires the U.S. EPA to promulgate emission standards for certain categories of HAPs. These standards must represent the application of the maximum achievable control technology (MACT). Categories subject to MACT include major sources and other sources found to warrant regulation. A major source is defined as a source that has the potential to emit 10 tons or more per year of any HAP or 25 tons or more per year of any combination of HAPs. Lesser quantities or different criteria can be established based on the potency of the HAP or other relevant factors.

The U.S. EPA has developed the Industrial Combustion Coordinated Rulemaking (ICCR) process to develop MACT standards for combustion sources. This process, started in 1996, gathers representatives of industry, environmental groups, and state and local regulatory agencies together to develop MACT standards for industrial and commercial heaters, boilers, and steam generators, gas turbines, and IC engines. The process is expected to take four years, and thus MACT standards for IC engines will not be promulgated until the year 2000.

3. State and District Requirements

The State and districts have had, for a number of decades, the authority to control air toxics if they pose a health hazard. However, the formal framework for setting emission limits for air toxics was not present until adoption of the Toxic Air Contaminant Identification and Control Act (AB 1807) in 1983. In 1987, passage of the Air Toxics "Hot Spots" Information and Assessment Act (AB 2588) expanded the role of the ARB and districts by requiring a statewide air toxics inventory and assessment, and notification of local residents of significant risk from nearby sources of air toxics. In 1992, SB 1731 required owners of certain significant risk facilities identified under AB 2588 to reduce the risk below the level of significance.

California has also taken action to reduce emissions of air toxics from on-road vehicles by the adoption of regulations requiring the production and use of cleaner burning diesel and gasoline fuels. When these fuels are used in stationary IC engines, emissions of toxic substances tend to be lower than when conventional diesel and gasoline are used. For gasoline engines, this reduction in toxicity is estimated to be about 30 to 40 percent. However, for diesel engines this reduction has not been quantified, as the interaction between gaseous and particulate matter constituents of diesel exhaust and the effect this interaction may have on human exposure is not well understood. The switch to California diesel fuel in 1993 resulted in an 82 percent reduction in sulfur dioxide emissions, a 25 percent reduction in particulate matter, and a 7 percent reduction in oxides of nitrogen emissions. In addition, many of the toxic substances found in diesel fuel are aromatics, and the diesel fuel specifications require the aromatics content of diesel fuel to be reduced to 10 percent, compared to a content of approximately 30 percent content prior to 1993. However, small refiners are allowed to have an aromatics content of 20 percent, and larger refiners are allowed to use alternative formulations that result in the same emissions of criteria pollutants. These alternative formulations typically contain greater amounts of aromatics.

4. Emission Rates of HAPs/TACs

A number of sources are available for estimating the emission rates for HAPs and TACs from IC engines. Using the emission factor recommended in the CAPCOA AB 2588 Risk Assessment Guidelines, the 10 tons per year major source threshold may be exceeded if a facility has natural gas-fired engines with a combined rating exceeding about 8,000 horsepower. If this major source threshold is exceeded, the engine is subject to federal MACT standards. More recent source testing of engines using natural gas, landfill gas, or field gas indicates the 10 tons per year threshold may be exceeded if a facility has engines with a combined rating as low as 4,000 horsepower. This is a worse plausible case, though, as these tests also indicate some facilities may not exceed 10 tons until the combined horsepower rating is as high as

200,000. These data demonstrate that emission rates of HAPs can vary greatly, depending on the type of gaseous fuel, and the design and operating parameters of each individual engine.

For diesel engines, the AB 2588 emission factors indicate the 10 tons per year major source threshold is not exceeded until a facility has engines with a combined rating of about 25,000 horsepower. More recent source testing of diesel engines indicates 10 tons may be exceeded if a facility has engines with a combined rating as low as 300 horsepower. These tests also indicate that some facilities with a combined horsepower rating as high as 5,000 may not exceed the threshold of 10 tons. These data demonstrate that emission rates of HAPs can vary greatly, depending on the design and operating parameters of the diesel engine.

5. Control of HAPs/TACs

a. Gaseous Fuel-Fired IC Engines

The toxic substances of most concern emitted from stationary engines burning gaseous fuels are VOCs. These VOCs are the result of incomplete combustion, and can be reduced by methods that either improve combustion inside the engine or destroy VOCs in the exhaust. The VOC emission limits found in this proposed determination will help limit emissions of toxic compounds that are also VOCs.

One of the more popular and effective VOC exhaust control methods for IC engines is the oxidation catalyst. Oxidation catalysts have been shown to reduce VOC emissions by over 90 percent for natural gas-fired engines. Reductions in toxic substances are not well documented for oxidation catalysts, but it is believed the percentage reduction for VOCs is similar to the percentage reduction for toxic substances that are also VOCs.

Engine modifications that promote complete combustion will reduce emissions of VOCs, thereby also reducing emissions of toxic substances that are VOCs. These engine modifications for natural gas-fired engines include operation of the engine with a lean (but not excessively lean) air/fuel ratio, and the use of improved ignition systems. However, operating an engine slightly lean will tend to maximize NOx emissions.

Emissions of particulate matter are generally very low for a properly operating spark-ignited engine. Particulate matter emissions from spark-ignited engines can be minimized by assuring that the air/fuel ratio is not overly rich and the fuel is low in sulfur content. Commercial natural gas, commercial LPG, and California cleaner burning gasoline are all extremely low in

sulfur. For fuels high in sulfur such as waste gases, emissions of particulate matter can be minimized by scrubbing the sulfur from the fuel before it is introduced into the engine.

b. Diesel-Fired Engines

The toxic substances of most concern from diesel engines are VOCs and particulate matter. Controls that reduce VOCs or particulate matter emissions will also tend to reduce emissions of toxic substances. Several different types of controls can be used to reduce emissions of toxics. These include cleaner fuels, combustion modifications, and exhaust controls. Particulate matter emissions can be reduced by about 25 percent by using California diesel fuel, which has a lower sulfur and aromatics content than other diesel fuels. Engine modifications that can reduce both VOC emissions and particulate matter emissions include the use of turbocharging, ceramic coatings, replacement of worn fuel injectors, use of improved injectors, installation of equipment that limits power output, and installation of equipment that limits fuel injected during rapid engine acceleration.

Exhaust controls that reduce emissions of toxics from diesel engines include catalysts and particulate traps. Oxidation catalysts reduce VOC emissions typically by 30 to 80 percent and particulate matter emissions typically by 40 to 50 percent. Recent data also shows selective catalytic reduction (SCR) systems also reduce emissions of VOCs and toxics.

Particulate traps on diesel engines can reduce particulate matter emissions by over 90 percent, and also tend to reduce VOC emissions. These traps must be regenerated periodically, generally by thermal destruction of the collected particulate matter. Most of the particulate matter is composed of carbon and hydrocarbons, and during thermal destruction these substances are converted into carbon dioxide and water vapor.

Particulate traps are still in the development stage. The first generation of traps used electric heaters to regenerate the trap. These first generation traps were expensive, complex, and ineffective if poorly maintained. Alternatives to electric heating are being pursued. These alternatives either reduce the temperature needed to regenerate the trap or increase the temperature at the trap. Temperature reduction options include the use of a catalytic combustor in front of or on the filter, and the use of fuel additives. As an added benefit, use of a catalytic combustor reduces CO and VOC emissions. There are over 30 engines equipped with particulate traps in Europe that have operated for over four years. All of these systems use a fuel burner for regeneration. Cost is typically $30 to $50 per horsepower.

One NOx reduction method for diesel engines, cyanuric acid, also reduces particulate matter and VOC emissions substantially. The proponent for this control method has performed tests that reportedly show the toxicity of diesel exhaust is substantially reduced by the use of this method.

It should also be noted that some NOx control methods such as injection timing retard and exhaust gas recirculation tend to increase particulate matter emissions. Thus, these methods may increase emissions of toxic substances. Consideration should be given to these potential increases in emissions when applying controls for NOx.

REFERENCES

1. "Evaluation of NOx Control Technologies for Gas-Fired Internal `Reciprocating' Combustion Engines," Final Report, prepared for Santa Barbara County Air Pollution Control District by Arthur D. Little, Inc., March 6, 1989.

2. "Evaluation of NOx Control Technologies for Gas-Fired Internal Combustion Engines," Technical Attachments, prepared for Santa Barbara County Air Pollution Control District by Arthur D. Little, Inc., March 6, 1989.

3. "Stationary Internal Combustion Engines," Compliance Assistance Program, Compliance Division, Air Resources Board, August, 1990.

4. "Alternative Control Techniques Document -- NOx Emissions from Stationary Reciprocating Internal Combustion Engines," Emission Standards Division, U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Air Quality Planning and Standards, Research Triangle Park, July, 1993.

5. Final Report "Evaluation of NOx Control Techniques for Gas-Fired Internal Combustion Engines," prepared for the County of Santa Barbara Air Pollution Control District by Arthur D. Little, Inc., November, 1989.

6. Phone conversation with Daniel W. Parker of General Plasma, East Windsor, Connecticut, January 13, 1993.

7. Draft Final Report "Review and Recommendation of Diesel Engine NOx Reduction Study," prepared for the Santa Barbara County Air Pollution Control District by Southwest Research Institute, Project No. 03-2888, August 16, 1989.

8. "Crew and Supply Boat NOx Control Development Program," prepared by Santa Barbara County Air Pollution Control District with technical assistance from Arthur D. Little, Inc., June, 1987.

9. "Application of RAPRENOX to NOx Control in Diesel Generators," Robert A. Perry, Technor, Inc., Cooperative Clean Air Technology Proceedings, March 29 to April 1, 1992, Santa Barbara, Air & Waste Management Association.

REFERENCES (continued)

10. "Near Term Emission Reduction Technology for Stationary, Natural Gas Fueled Engines," Robert Stachowicz, Waukesha Engine Division, Dresser Industries, Inc., Cooperative Clean Air Technology Proceedings, March 29 to April 1, 1992, Santa Barbara, Air & Waste Management Association.

11. Letter from Mike Lake of the San Diego County Air Pollution Control District to Wilfred K. Nagamine, Hawaii State Department of Health, dated August 23, 1991.

12. "Alternative NOx Controls for Stationary Internal Combustion Engines," by SCEC, Workshop on NOx Control for Stationary Sources, March 25-6, 1993, Ventura, California, Air and Waste Management Association, Channel Islands Chapter.

13. "A Study to Determine the Effect of Injection Retard on Diesel Generator Emissions from an Active Drill Ship," by E. Robert Fanick, Final Report, May, 1983, Southwest Research Institute.

14. Ventura County Air Pollution Control District, "Staff Report - Proposed Revision to Rule 74.9 Stationary Internal Combustion Engines," December, 1993.

15. Santa Barbara County Air Pollution Control District, "Staff Report - Proposed Rule 333 - Control of Emissions from Reciprocating Internal Combustion Engines," December, 1991.

16. "Gas Engine Emissions Technology," Form 536, Waukesha Engine Division, Dresser Industries, Inc., Waukesha, Wisconsin, October 1993.

17. "Staff Report Proposed Rule 1110.2 - Emissions from Gaseous- and Liquid-Fueled Internal Combustion Engines," A. Rawuka, SCAQMD, July 11, 1990.

18. "Draft Staff Report for Proposed Amended Rule 1110.2 -- Emissions from Gaseous- and Liquid-Fueled Engines," Kien Huynh and Gregory Wood, SCAQMD, December 7, 1995.

19. Staff Report for South Coast Air Quality Management District Proposed Rule 1110.2 - Emissions from Gaseous and Liquid Fueled Internal Combustion Engines, July 11, 1990.

REFERENCES (continued)

20. Personal Communication, George Amos, Vice President, ENOX Technologies, Inc., Natick, Massachusetts, August 9, 1995.

21. Personal Communication, B.L. Mikkelsen, Emissions Plus Inc., Houston, Texas, January 12, 1996.

22. Personal Communication, Gregory M. Beshouri, Advanced Engine Technologies Corp, Oakland, California, May 17, 1996.

23. Ventura County Air Pollution Control District, "Phase III Rule Effectiveness Study, VCAPCD Rule 74.9, Stationary Internal Combustion Engines," October 1, 1994.

24. Letter from Douglas Grapple, Air Quality Engineer, Santa Barbara County APCD, to Don Koeberlein, Air Resources Board, dated June 11, 1996.

25. "Emission Control Technology for Stationary Internal Combustion Engines: Status Report," October 1995, Manufacturers of Emissions Controls Association (MECA).

26. "Technical Feasibility of Reducing NOx and Particulate Emissions from Heavy-Duty Engines," Final Report, April 30, 1993, Contract No. A132-085, Prepared for California Air Resources Board by Acurex Environmental Corporation.

27. San Luis Obispo County Air Pollution Control District Staff Report, Rule 431, Stationary Internal Combustion Engines, November 13, 1996.

28. "Children's Hospital Cost-Effectiveness for NSCR," Godfrey Aghoi, San Diego County APCD, June 14, 1996.

29. "Demonstration of Lean NOx Catalytic Converter Technology on a Heavy-Duty Diesel Engine," Contract Number 92-310, Prepared for the California Air Resources Board by Martin J. Heimrich of the Southwest Research Institute, May 1996.

REFERENCES (continued)

30. "NOx and VOC Species Profiles for Gas Fired Stationary Source Combustion Sources," Contract number A132-104, prepared for the ARB by Energy and Environmental Research, January 19, 1994.

31. "Controlling Emissions from Stationary Internal Combustion Engines with Catalytic Technology," Johnson Matthey, Catalytic Systems Division, Environmental Products, 1995.

32. Personal communication, Michelle Platis, Miratech Corporation, Tulsa, Oklahoma, November 5, 1996.

33. "Selective Catalytic Reduction (SCR) Controls to Abate NOx Emissions," prepared by SCR Committee, Institute of Clean Air Companies, Inc., October 1994.

34. Personal communication, Joseph P. Aleixo, DCL Industries, Inc., Concord, Ontario, Canada, June 13, 1996.

35. Dale McKemmon, "Emission Control Technology for Off-Road Mobile Equipment," Exploring New Technologies for Clean Air Symposium, September 29 - October 1, 1997, Cal/EPA, ARB.

36. Personal communication, Doug Hennigan, Norton Chemical Process Products Corporation, October 23, 1997.

37. Letter from Douglas F. Grapple, Air Quality Engineer, Santa Barbara County APCD to Don Koeberlein, ARB, Subject: Draft Internal Combustion Engine RACT/BARCT, dated September 10, 1997.

38. Memo from Godfrey Aghoi, Associate Engineer, San Diego County APCD, to Don Koeberlein, ARB, Subject: Cost-Effectiveness of Internal Combustion Engines, dated October 8, 1997.

39. “Evaluation of Stationary Internal Combustion Engine Best Available Retrofit Control Technology Rule Proposed by the San Joaquin Valley Unified Air Pollution Control District,” Powers Engineering, Prepared for Western States Petroleum Association, September 19, 1995.

REFERENCES (continued)

40. "Emission Inventory of Agricultural Internal Combustion Engines Used for Irrigation in the SJVUAPCD," Preliminary Draft Report STI-95240-1569-PDR, by Richard Reiss, Lyle R. Chinkin, and Dana L. Coe of Sonoma Technology, Inc., and Charles DiSogra of Freeman, Sullivan & Co., Prepared for San Joaquin Valley Unified Air Pollution Control District, April 1996.

DRAFT

APPENDIX A

PROPOSED DETERMINATION OF RACT AND BARCT FOR STATIONARY IC ENGINES

ARB/SSD December 3, 1997

PROPOSED DETERMINATION OF REASONABLY AVAILABLE CONTROL TECHNOLOGY AND BEST AVAILABLE RETROFIT CONTROL TECHNOLOGY FOR STATIONARY INTERNAL COMBUSTION ENGINES

I. Applicability

Except as provided in Section IV. (Exemptions), the provisions of this proposed determination are applicable to all stationary internal combustion engines with a current or past rating of 50 brake horsepower or greater, or a maximum fuel consumption of :

0.37 million BTUs per hour or greater for turbocharged or supercharged diesel engines;
0.39 million BTUs per hour or greater for naturally aspirated diesel engines;
0.52 million BTUs per hour or greater for spark ignited engines.

[Note: The proposed determination exempts engines used in agricultural operations. This conforms to existing district rules, which also exempt agricultural engines. Health and Safety Code Section 42310(e) prohibits districts from requiring permits for agricultural engines. This prohibition does not preclude districts from controlling agricultural engines.]

II. Definitions

A. ***ANNUAL*** means any consecutive twelve month period.

B. ***CALENDAR YEAR*** means the time period from January 1 through December 31.

C. ***DIESEL ENGINE*** means a liquid or dual (liquid and gaseous) fueled engine designed to ignite its air/fuel mixture through the high temperatures generated by compression.

D. ***DISASTER OR STATE OF EMERGENCY*** means a fire, flood, earthquake, or other similar natural catastrophe.

E. ***DISTRIBUTED GENERATION*** refers to one or more IC engines used to generate electrical power that is either fed into the electric utility power grid or displaces power distributed by the electric utility. Distributed generation also refers to a mechanical drive system consisting of one or more IC engines and electric motors, where use of the IC engines or electric motors is interchangeable.

F. ***EMERGENCY STANDBY ENGINE*** is an engine which operates as a temporary replacement for primary mechanical or electrical power during an unscheduled outage. An engine shall not be considered to be an emergency standby engine if it is used for purposes other than: periodic maintenance, periodic readiness testing, unscheduled outages, or to supply power while maintenance is performed or repairs are made to the primary power supply.

G. ***ENGINE*** is any spark- or compression-ignited reciprocating internal combustion engine.

H. ***EXEMPT COMPOUNDS*** means carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, ammonium carbonate, and the following compounds:

(1) methane,
methylene chloride (dichloromethane),
1,1,1-trichloroethane (methyl chloroform),
trichlorofluoromethane (CFC-11),
dichlorodifluoromethane (CFC-12),
1,1,2-trichloro-1,,2,2-trifluoroethane (CFC-113),
1,2-dichloro-1,1,2,2-tetrafluoroethane (CFC)-114,
chloropentafluoroethane (CFC-115),
chlorodifluoromethane (HCFC-22),
1,1,1-trifluor-2,2-dichloroethane (HCFC-123),
1,1-dichloro-1-fluoroethane (HCFC-141b),
1-chloro-1,1-difluoroethane (HCFC-142b),
2-chloro-1,1,1,2-tetrafluoroethane (HCFC-124),
trifluoromethane (HFC-23),
1,1,2,2-tetrafluorethane (HFC-134),
1,1,1,2-tetrafluoroethane (HFC-134a),
pentafluorethane (HFC-125),
1,1,1-trifluoroethane (HFC-143a),
1,1-difluoroethane (HFC-152a),
cyclic, branched, or linear completely methylated siloxanes,
the following classes of perfluorocarbons:

(a) cyclic, branched, or linear, completely fluorinated alkanes;
(b) cyclic, branched, or linear, completely fluorinated ethers with no unsaturations;
(c) cyclic, branched, or linear, completely fluorinated tertiary amines with no unsaturations; and
(d) sulfur-containing perfluorocarbons with no unsaturations and with the sulfur bonds to carbon and fluorine, and

(2) The following low-reactive organic compounds which have been exempted by the U.S. EPA:

acetone
ethane
parachlorobenzotrifluoride (1-chloro-4-trifluoromethyl benzene).

Methylated siloxanes and perfluorocarbon compounds shall be assumed to be absent from a product or process unless a manufacturer or facility operator identifies the specific individual compounds (from the broad classes of methylated siloxanes and perfluorocarbon compounds) and the amounts present in the product or process and provides a validated test method which can be used to quantify the specific compounds.

I. ***EXHAUST CONTROLS*** are devices or techniques used to treat an engine's exhaust to reduce emissions, and include (but are not limited) to catalysts, afterburners, reaction chambers, and chemical injectors.

J. ***FACILITY*** is one or more parcels of land in physical contact, or separated solely by a public roadway:

(1) all of which are under the same ownership or operation, or which are owned or operated by entities which are under common control; and
(2) belong to the same industrial grouping, either by virtue of falling within the same two-digit standard industrial classification code or are part of a common industrial process, manufacturing process, or connected process involving a common raw material; and
(3) upon which one or more stationary engines operate.

K. ***HIGH FUEL CONSUMPTION*** means: (1) for a spark-ignited engine, the consumption of 180 million BTUs or more of fuel per calendar year; (2) for a diesel engine, the consumption of 25,000 gallons or more of diesel per calendar year; (3) for a dual fuel engine, the consumption of 3,400 million BTUs or more of total fuel per calendar year. Diesel engines in crane applications shall not be considered high fuel consumption engines.

L. ***LEAN-BURN*** means a spark-ignited engine whose manufacturer's recommended operating specifications result in exhaust containing at least four percent oxygen by volume as it exits the combustion chamber.

M. ***LOW FUEL CONSUMPTION*** means: (1) for a spark-ignited engine, the consumption of less than 180 million BTUs of fuel per calendar year; (2) for a diesel engine, the consumption of less than 25,000 gallons of diesel per calendar year, or the application of the engine in a crane; (3) for a dual fuel engine, the consumption of less than 3,400 million BTUs of total fuel per calendar year.

N. ***NEW NONROAD ENGINE*** means a new nonroad engine as defined by the U.S. EPA in 40 CFR Part 89, Subpart A, Section 89.2.

O. ***PPMV*** is parts per million by volume at dry conditions.

P. ***RATED BRAKE HORSEPOWER (bhp***) of an engine is the maximum continuous rating for that engine specified by the manufacturer, based on SAE test 1349 or a similar standard, without taking into account any deratings.

Q. ***RICH-BURN*** means a spark-ignited engine whose manufacturer's recommended operating specifications result in exhaust containing less than four percent oxygen by volume as it exits the combustion chamber.

R. ***STATIONARY INTERNAL COMBUSTION ENGINE*** is an engine which is not self propelled and is operated at a single facility.

S. ***VOLATILE ORGANIC COMPOUND (VOC)*** is any compound containing at least one atom of carbon, except exempt compounds.

T. ***WASTE GAS*** is any gaseous fuel composed primarily of landfill gas, sewage treatment digester gas, or a combination of the two.

III. Requirements

RACT:

A. Emissions, corrected to 15 percent oxygen on a dry basis and averaged over 15 minutes, shall not exceed the following limits for the appropriate engine type:

Engine Type	% Control	or	PPMV at 15% O_2*		
	NOx		NOx	VOC	CO
Spark-Ignited Engines					
-Low Fuel Consumption					
All Fuels	---		350	750	4500
-High Fuel Consumption					
Rich-Burn	90		50	250	4500
Lean-Burn	80		125	750	4500
Diesel Engines	---		350	750	4500

* For NOx, either the percent control or the ppmv limit must be met by each engine. The percent control option applies only if a percentage is listed, and applies only to engines using exhaust controls. The percent control shall be determined by measuring concurrently the NOx concentration upstream and downstream from the exhaust control. The ppmv limits for VOC and CO apply to all engines.

BARCT:

B. Emissions, corrected to 15 percent oxygen on a dry basis and averaged over 15 minutes, shall not exceed the following limits for the appropriate engine type:

Engine Type	% Control	or	PPMV at 15% O_2*		
	NOx		NOx	VOC	CO
Spark-Ignited Engines					
-Low Fuel Consumption	---		350	750	4500
-High Fuel Consumption					
Rich-Burn, Waste Gas Fueled	90		50	250	4500
Rich-Burn, All Other Fuels	96		25	250	4500
Lean-Burn	90		65	750	4500
Diesel Engines					
-Low Fuel Consumption	---		350	750	4500
-High Fuel Consumption	90		80	750	4500

* For NOx, either the percent control or the ppmv limit must be met by each engine. The percent control option applies only if a percentage is listed, and applies only to engines using exhaust controls. The percent control shall be determined by measuring concurrently the NOx concentration upstream and downstream from the exhaust control. The ppmv limits for VOC and CO apply to all engines.

IV. Exemptions

A. The provisions of this rule shall not apply to:

(1) The operation of any engine while being used to preserve or protect property, human life, or public health during the existence of a disaster or state of emergency, such as a fire or flood.

(2) Engines used directly and exclusively by the owner or operator for agricultural operations necessary for the growing of crops or raising of fowl or animals.

(3) Engines registered under the Statewide Portable Equipment Registration Program pursuant to Sections 2450-2465, Articles 5, Title 13, California Code of Regulations.

(4) New nonroad engines.

B. The provisions of this rule, except for Section VII.B.(2), shall not apply to:

(1) Engines that are not used to generate electrical power or whose operation do not reduce power purchased by a facility, provided total annual hours of operation do not exceed 100 hours as determined by a nonresettable elapsed operating time meter; or
(2) Emergency standby engines that, excluding periods of operation during unscheduled power outages, do not exceed 100 hours of operation annually as determined by a nonresettable elapsed operating time meter.

V. Compliance Schedule

The owner or operator of one or more stationary internal combustion engines shall comply with the applicable parts of Sections III. and VII. of this rule in accordance with the following schedule:

A. For each engine to be permanently removed from service and not replaced by another IC engine:

(1) by (6 months after adoption date), submit a statement to the Air Pollution Control Officer identifying the engine to be removed;
(2) by (3 years after adoption date), remove or replace the engine.

B. For low fuel consumption engines and diesel engines (low fuel consumption diesel engines only in the case of BARCT requirements):

(1) by (6 months after adoption date), submit an emission control plan for Air Pollution Control Officer approval;
(2) by (9 months after adoption date), receive approval from the Air Pollution Control Officer for the emission control plan;
(3) by (1 year after adoption date), have engines under compliance in accordance with an approved emissions control plan.

For all other engines subject to this rule:

(1) by (6 months after adoption date), submit an emission control plan for Air Pollution Control Officer approval;

(2) by (9 months after adoption date), receive approval from the

Air Pollution Control Officer for the emission control plan;

(3) by (1 year after adoption date), have all required applications for permits to construct submitted and deemed complete by the Air Pollution Control Officer;

(4) by (2 years after adoption date), have engines and stack modifications, including applicable monitoring systems, under compliance in accordance with an approved emission control plan.

VI. Test Methods

A. Oxygen content, oxides of nitrogen emissions, and carbon monoxide emissions for compliance source tests shall be determined by using ARB Method 100.

B. Volatile organic compound emissions for compliance source tests shall be determined by using ARB Method 422.

VII. Administrative

A. Emission Control Plan

The owner or operator of a stationary internal combustion engine subject to both Sections III and V.B. of this rule shall submit an emissions control plan to the Air Pollution Control Officer for approval.

(1) The plan shall describe all actions, including a schedule of increments of progress, which will be taken to meet the applicable emissions limitations in Section III. and the compliance schedule in Section V.B. Such plan shall also contain the following information for each engine where applicable:

(a) district permit or identification number,

(b) name of engine manufacturer,

(c) model designation,

(d) rated brake horsepower,

(e) engine type and fuel type (e.g., natural gas-fired rich-burn),

(f) total hours of operation in the previous one-year period, including typical daily operating schedule.

(g) fuel consumption (cubic feet of gas or gallons of liquid) for the previous one year period,

(h) stack modifications to facilitate continuous in-stack monitoring and source testing,

(i) type of controls to be applied, including in-stack monitoring specifications.

(j) the applicable emission limits, and

(k) documentation showing existing emissions of NOx, VOC, and CO.

(2) The emission control plan shall include an inspection and monitoring (I&M) plan. The I&M plan shall include procedures requiring the owner or operator to establish ranges for control equipment parameters, engine operating parameters, and engine exhaust oxygen concentrations that source testing has shown result in pollutant concentrations within the rule limits. The inspection and monitoring plan shall include periodic emissions checks by a procedure specified by the Air Pollution Control Officer. All inspections and monitoring shall take place in conformance with a regular inspection schedule listed in the I&M plan. The I&M plan shall also include preventive and corrective maintenance procedures. Before any change in operations can be implemented, the I&M plan must be revised as necessary, and the revised plan must be submitted to and approved by the Air Pollution Control Officer.

B. Continuous Monitoring and Recordkeeping

(1) The owner or operator of one or more stationary internal combustion engines subject to both Sections III and V.B. of this rule shall meet the following requirements:

(a) For each stationary internal combustion engine with a rated brake horsepower of 1,000 or greater and which is permitted to operate more than 2,000 hours per calendar year, the owner or operator shall install, operate, and maintain in calibration a continuous NOx and O_2 monitoring system, as approved by the Air Pollution Control Officer, to demonstrate compliance with the emissions limits of this rule. This system shall determine and record exhaust gas NOx and O_2 concentrations in ppmv, corrected to 15 percent oxygen. Continuous emissions monitors shall meet the applicable federal requirements described in 40 CFR Part 60. These include the performance specifications found in Appendix B, Specification 2, the quality assurance requirements found in Appendix F, and the reporting requirements of Parts 60.7(c), 60.7(d), and 60.13.

(b) Data collected through the I&M plan described in Section VII.A.(2) shall be in a form approved by the Air Pollution Control Officer, and shall have retrieval capabilities as approved by the Air Pollution Control Officer. The monitoring system described in Section VII.B.(1) shall have data gathering and retrieval capability approved by the Air Pollution Control Officer. All data collected pursuant to the requirements of Section VII.A.(2) and VII.B.(1) shall be maintained for at least two years and made available for inspection by the Air Pollution Control Officer or the Officer's designee.

(c) The owner or operator shall arrange for and assure that an emissions source test is performed on each stationary internal combustion engine at least once every 8,760 hours of operation or every 24 months, whichever is the shorter time period. In addition, the owner or operator shall arrange for and assure that an initial emissions source test is performed on each stationary internal combustion engine to verify compliance with Section III. by the date specified in Section V.B.(4). Prior to any source test required by this rule, a source test protocol shall be prepared and submitted to the Air Pollution Control Officer. In addition to other information, the source test protocol shall describe which critical parameters will be measured, and how the appropriate range for these parameters shall be established and incorporated into the I&M plan described in Section VII.A.(2). The source test protocol shall be approved by the Air Pollution Control Officer prior to any testing. VOC shall be reported as methane. VOC, NOx, and CO concentrations shall be reported in ppmv, corrected to 15 percent oxygen. For engines using exhaust controls, NOx shall also be reported as a percent reduction across the control device.

(2) Any engine subject to this rule shall be required to install a nonresettable fuel meter and a nonresettable elapsed operating time meter. The owner or operator shall assure that these required meters are maintained in proper operating condition, and shall maintain an engine operating log that includes, on a monthly basis, the total hours of operation and type (e.g, natural gas, diesel) and quantity of fuel used. For emergency standby engines, the hours of operation during unscheduled power outages shall also be reported. This information shall be available for inspection at any time, and shall be submitted to the Air Pollution Control Officer at the end of each calendar year in a manner and form approved by the Air Pollution Control Officer.

DRAFT

APPENDIX B

DESCRIPTION OF IC ENGINE CONTROLS

ARB/SSD December 3, 1997

Combustion of fossil fuels results in emissions of criteria pollutants and their precursors (i.e., NOx, CO, particulate matter, VOC, and sulfur oxides (SOx)). Controls for one pollutant sometimes increases the emissions of one or more other pollutants. If this occurs, controls can often be used for these other pollutants which will fully mitigate the increase. SOx is generally controlled by limiting the sulfur content of the fuel and is not discussed further in this proposed determination, except as it affects emissions of other pollutants.

The following discussion of controls emphasizes the control of NOx. NOx emissions from stationary engines are generally far greater than for other pollutants.

NOx is generated in internal combustion engines almost exclusively from the oxidation of nitrogen in the air (thermal NOx) and from the oxidation of fuel-bound nitrogen (fuel NOx). The generation of fuel NOx varies with the nitrogen content of the fuel and the air/fuel ratio. The generation of thermal NOx varies with the air/fuel ratio, flame temperature, and residence time. Most fuels used in IC engines have relatively low fuel-bound nitrogen, so the principal NOx generation mechanism is thermal NOx. Even in cases where a high nitrogen content fuel such as crude oil or residual fuel oil is used, thermal NOx generation is generally far greater than fuel NOx generation due to the high combustion temperatures present.

There are probably more different types of controls available to reduce NOx from IC engines than for any other type of NOx source. These controls can be placed into one of three general categories: combustion modifications, fuel switching, and post combustion controls. These controls are discussed in the following sections.

A. Combustion Modifications

Combustion modifications can reduce NOx formation by using techniques that change the air/fuel mixture, reduce peak temperatures, or shorten the residence time at high temperatures. The most frequently used combustion modifications include retarding the injection or ignition timing, leaning the air/fuel ratio, adding a turbocharger and aftercooler, and adding exhaust gas recirculation.

Emissions of CO, particulate matter, and VOC are generally the result of incomplete combustion. They can be controlled by combustion modifications that increase oxygen, temperature, residence time at high temperatures, and the mixing of air and fuel. Note, however, that many of these modifications tend to increase NOx emissions. Care must be taken when applying these modifications to assure that reductions in one pollutant do not result in an unacceptable increase in other pollutants. These pollutants can also be controlled by post combustion controls such as oxidation catalysts and particulate traps.

1. Injection Timing Retard

Applicability: This technique can be used on most compression-ignited (CI) engines. It has been used extensively on a number of engine makes and models.

Principle: In CI engines, maximum efficiency and power output occur when fuel is injected just before the combustion air is fully compressed. If the injection can be delayed (i.e., retarded) slightly, more of the combustion will take place as the piston begins its downward movement, which reduces both the magnitude and duration of peak temperatures.

Typical Effectiveness: 15 to 30 percent NOx reduction for a 4 degree retard on direct injection engines; one percent NOx reduction per degree of retard on indirect injection engines.

Limitations: If timing is retarded much beyond about four degrees of crankshaft rotation from manufacturer's specifications, operational problems can occur. These problems include decreased power, poorer fuel economy and throttle response, and increased emissions of particulate matter, CO, and VOC. This technique cannot be used on all CI engines. On some engines injection timing is not adjustable. On other engines, any timing retard may result in operational problems such as excessive smoke. Lack of adjustment and smoking problems are more prevalent for older and naturally aspirated diesel engines. Smoking problems are generally most severe when the throttle is opened rapidly. This problem can be minimized by adding a throttle delay mechanism. For some turbocharged engines, the exhaust turbine may require rematching when timing is retarded. However, for most engines, retarding the injection timing four degrees is a relatively simple process that will not result in any significantly adverse effects. Exhaust temperatures increase when injection is retarded, which can cause exhaust valves to wear excessively.

Other Effects: Fuel consumption increases by about one percent per degree of retard. Emissions of pollutants other than NOx tend to increase when injection timing is retarded, especially particulate matter emissions. However, at 4 degrees of retard, these emissions increases are negligible for most engines.

Costs: Compared to other methods, injection timing retard has low capital and operating costs. In most cases, the timing change can be performed by a mechanic within a few hours for a cost that does not exceed $300. Operating costs are generally limited to increased fuel consumption. If a throttle delay mechanism is needed, costs of installation varies with the age of the engine, with older engines costing more than newer ones. Costs for installing a throttle delay mechanism are typically $350 to $400 for most Detroit Diesel engines.

2. Ignition Timing Retard

Applicability: This technique can be used on all spark-ignited (SI) engines. The technique has been widely used on motor vehicle engines, but is less popular on stationary source engines.

Principle: This technique is essentially identical to injection timing retard, except it applies to SI engines rather than CI engines. The ignition is retarded in SI engines by delaying the electrical pulse to the spark plug. As a result, the spark plug fires later, resulting in more of the combustion taking place as the piston begins its downward movement. This reduces both the magnitude and duration of peak temperatures.

Typical Effectiveness: In general, ignition timing retard is less effective than injection timing retard. Thus, NOx reductions for ignition timing retard are less than the typical range of 15 to 30 percent for injection timing retard.

Limitations: SI engines are more sensitive than CI engines to operational problems associated with timing retard, and SI engines with excessive retard tend to misfire and exhibit poor transient performance.

Other Effects: The effects of ignition timing retard are similar to injection timing retard. Ignition timing retard will result in greater fuel consumption and higher exhaust temperatures, which could cause excessive exhaust valve wear. The maximum power output of the engine is also reduced, but this reduction is generally minor.

Costs: This method has relatively low capital and operating costs. The cost of adjusting timing to retard the ignition should be less than the corresponding procedure (injection timing retard) on a CI engine.

3. Air/Fuel Ratio Changes

Applicability: This technique can be used on all spark-ignited (SI) engines, and has been used extensively on a wide variety of engines.

Principle: NOx formation is a strong function of the air/fuel ratio. Emissions of CO and VOC are also strong functions of the air/fuel ratio. Stoichiometry is achieved when the air/fuel ratio is such that all the fuel can be fully oxidized with no residual oxygen remaining. NOx formation is highest when the air/fuel ratio is slightly on the lean side of stoichiometric (see Figure 4). At this point, both CO and VOC are relatively low. Adjusting the air/fuel ratio toward either leaner or richer mixtures from the peak NOx formation air/fuel ratio will reduce NOx formation.

In the case of leaner mixtures, the excess air acts as a heat sink, reducing peak temperatures, which results in reduced NOx formation. The excess air also allows more oxygen to come into contact with the fuel, which promotes complete combustion and reduces VOC and CO emissions. As the mixture continues to be leaned out, the reduced temperatures may result in a slight increase in CO and VOC emissions. For extremely lean mixtures, misfiring will occur, which increases VOC emissions dramatically.

Operating the engine on the lean side of the NOx formation peak is often preferred over operating rich because of increased fuel efficiencies associated with lean operation. When adjusting the air/fuel ratio, once an engine is leaned beyond the peak NOx air/fuel ratio, there is approximately a 5% decrease in NOx for a 1% increase in intake air. However, this rate of decrease in NOx becomes smaller as the mixture becomes leaner. Leaning the mixture beyond the optimal air/fuel ratio associated with peak fuel efficiency will result in increased fuel consumption. Compared to the most efficient air/fuel ratio, there is a fuel consumption penalty of about 3 percent when an engine is leaned sufficiently to reduce NOx by 50 percent. Fuel consumption increases exponentially if the mixture is leaned further.

NOx formation will also decrease if the mixture is richened from the peak NOx air/fuel ratio. However, the effect on NOx is generally not as great as that associated with leaning the mixture. With richer mixtures, the available oxygen preferentially combines with the fuel to form carbon dioxide (CO_2) and water (H_2O), leaving less oxygen available to combine with nitrogen to form NOx. A mixture richer than stoichiometric will result in incomplete combustion. Nearly all the oxygen will then combine with the fuel, emissions of CO and VOC will increase, and reductions in peak temperatures will reduce NOx formation. There is a very rapid exponential increase in CO and VOC emissions as the mixture becomes richer than stoichiometric.

The use of very lean air/fuel ratios may result in ignition problems. For this reason, techniques designed to improve ignition are often combined with lean air/fuel ratios to control NOx emissions and avoid increases in VOC emissions. These other techniques are described on the following pages.

Typical Effectiveness: When leaning of the mixture is combined with other techniques such as clean burn retrofit, NOx reductions greater than 80 percent are achievable, along with reductions in CO and VOC emissions. If extremely lean mixtures are used in conjunction with engine derating, NOx reductions well above 80 percent (less than 65 ppmv) are achievable. For extremely lean mixtures the resulting reduced temperatures will tend to inhibit oxidation, which will increase CO and VOC emissions to some degree.

For rich mixtures, the NOx reduction potential is not as great as reductions for lean mixtures. As the mixture is richened, emissions of CO and VOC increase to unacceptable levels before the NOx decreases to levels achieved by leaning the mixture.

Limitations: If the air/fuel mixture is richened excessively, emissions of CO and VOC increase dramatically. If the air/fuel ratio is leaned excessively, the flammability limit may be exceeded, resulting in misfiring. When an engine misfires (i.e., fails to fire), uncombusted fuel enters the exhaust, which dramatically increases VOC emissions.

Other effects: None known.

Costs: Changing the air/fuel ratio of a SI engine should cost no more than retarding the injection timing for a diesel engine (i.e., no more than several hundred dollars). There is generally a fuel penalty for rich-burn engines that are richened, but leaning the mixture may reduce fuel consumption. These fuel effects vary with the engine and the degree of change in the air/fuel mixture.

4. Clean Burn Retrofit

Applicability: This method can be used on all SI engines, and has had wide applications on a variety of engines.

Principle: This method is used to enhance the effectiveness of the air/fuel ratio method described previously. As indicated previously in the discussion of air/fuel ratio changes, leaning the air/fuel mixture from the optimal NOx producing ratio will reduce NOx formation. The leaner the mixture, the lower the NOx emissions. However, to obtain substantial reductions in NOx emissions, engine modifications are needed to assure that the fuel will ignite and to minimize any fuel consumption penalties. A number of engine manufacturers and NOx control equipment manufacturers offer retrofit kits for some makes and models of lean-burn and rich-burn engines that allow these engines to operate on extremely lean mixtures to minimize NOx emissions. These retrofits are often referred to as "clean burn" retrofits.

On smaller engines, the cylinder head can be redesigned to promote improved swirl patterns which result in thorough mixing. On larger engines, the use of a precombustion chamber (also referred to as a prechamber) is needed to ignite the lean mixture. In this latter case, engines have two combustion chambers, a main chamber and a prechamber connected to the main chamber (see Figure 5). Combustion begins in the smaller prechamber, which contains the spark plug and a rich air/fuel mixture. Combustion propagates into the larger main chamber, which contains a lean air/fuel mixture. The resulting peak temperatures are lower due to: 1) the rich ignition mixture, 2) heat transfer losses as combustion proceeds into the main chamber, and 3) the dilution effects of the excess air.

Many precombustion chamber retrofits consist of replacing the existing engine heads with new heads. However, some low cost prechamber retrofits are designed to use the existing engine's head, with the prechambers fitted into the existing spark plug hole. Other prechamber retrofits consist of a modified spark plug instead of a separate prechamber. The modified spark plug has a small, built-in fuel nozzle which injects fuel toward the spark plug electrode.

In order to achieve these leaner air/fuel ratios, additional amounts of air must be introduced into the engine when using a given amount of fuel. For naturally aspirated engines, a turbocharger often must be added to provide the additional air. In other cases, the existing turbocharger may have to be replaced or modified to increase the air throughput.

Other equipment may also be used in a clean burn retrofit, such as a high energy ignition system to eliminate or minimize misfiring problems associated with lean operation, a new or modified aftercooler, and an air/fuel ratio controller. This equipment is described in more detail on the following pages.

Typical Effectiveness: For natural gas-fired engines, in almost all cases NOx emissions can be reduced to less than 130 parts per million (ppm) (i.e., greater than an 80 percent reduction over uncontrolled levels) with little or no fuel penalty. If engine parameters are adjusted and carefully controlled and the maximum power output of the engine is derated, sustained emissions below 65 ppm are achievable.

Limitations: NOx reductions of roughly 80 percent over uncontrolled levels are achievable with little or no fuel penalty. However, if the engine is leaned further to reduce emissions by more than about 80 percent, the fuel penalty increases exponentially. In some cases, a turbocharger may be needed to provide increased air flow, but a properly sized turbocharger may not be available for a retrofit. In other cases, the available retrofit parts may not allow the engine to produce the same maximum power, and the engine must be derated. Beyond a certain degree of leaning (and NOx reduction), misfiring will become a problem.

In some cases, it may be cheaper to replace an existing engine with a new clean burn engine, rather than install a clean burn retrofit kit. This is especially true if the retrofit kit has to be developed for that particular make and model of engine, or if the existing engine is old, inefficient, or unreliable.

Other effects: At extremely lean air/fuel ratios, VOC and CO emissions tend to increase slightly. Once the air/fuel mixture is sufficiently lean, misfiring may occur, in which case VOC emissions can increase substantially.

Costs: For the installation of precombustion chamber heads and related equipment on large (~ 2,000 horsepower) Cooper engines, capital costs are about $400,000 per engine, and installation costs are about $200,000. Costs are lower for smaller engines. In terms of dollars per rated brake horsepower (bhp), costs are about $250/bhp for the large engines, and tend to be higher than this for smaller engines.

For prechambers fitted inside the existing spark plug hole, capital costs are about $15,000 to $20,000 for engines in the 300 to 400 horsepower range. Capital costs for engines in the 2,000 horsepower range can exceed $200,000.

5. <u>Ignition System Improvements</u>

Applicability: This control method can be used on all SI engines. It has been applied to only a limited number of engines and engine types.

Principle: This method is used in conjunction with the use of lean air/fuel ratios to reduce NOx emissions. It allows leaner mixtures to be used without misfiring problems. As indicated previously, the leaner the air/fuel ratio, the lower the NOx emissions. However, at some point in leaning the mixture, lean misfire begins to occur, and further NOx reductions are impractical. In most engines during ignition, a nonuniform air/fuel mixture passes by the spark plug. In standard ignition systems, the spark plug's firing duration is extremely short. If the spark plug fires when this mixture is too lean to support combustion, a misfire occurs. If the spark plug fires multiple times, or for a longer period of time, there is a greater chance that the proper air/fuel mixture will pass by the spark plug and ignite the mixture. Improved ignition systems generally use a higher voltage to fire the spark plug, in addition to multiple or continuous sparking of the spark plug. This allows the use of leaner air/fuel ratios, resulting in lower NOx emissions.

Typical Effectiveness: Emission reductions from a combination of leaning of the air/fuel mixture and use of a continuous sparking ignition system approach but are generally less than a precombustion chamber retrofit. NOx emissions can generally be reduced to about 200 ppm.

Limitations: If the air/fuel ratio is leaned excessively, misfiring can occur. As with all methods involving leaning, the engine's maximum power rating may have to be reduced unless a turbocharger is retrofitted to naturally aspirated engines or the existing turbocharger is modified or replaced to increase the throughput of combustion air. In many cases, a separate retrofit kit must be developed for each make and model of engine, and only a few kits have been developed so far.

Other effects: At extremely lean air/fuel ratios, VOC and CO emissions tend to increase slightly. If the air/fuel mixture is leaned excessively, misfiring may occur, in which case VOC emissions can increase substantially.

Costs: Costs are about two-thirds that of a precombustion chamber retrofit involving head replacement. For large Cooper engines (~ 2000 horsepower), costs are about $400,000.

6. Prechamber Design

Applicability: Although both SI and CI engines can use prechambers, the operation, design, and principle are slightly different when used on CI engines. The use of prechambers on SI engines has been discussed earlier. For this discussion, we will focus on the application of prechambers to CI engines exclusively, where it is often called indirect injection. Several engine manufacturers have used prechambers in their CI (diesel) engines, but this design is not the most prevalent engine design.

Principle: When prechamber technology is applied to CI engines, the fuel injector is placed inside the prechamber. The prechamber design results in effectively retarding the timing, thereby reducing NOx emissions.

Typical Effectiveness: Diesel prechamber engines typically emit about 400 to 800 ppm of NOx, in comparison to uncontrolled direct injection diesels that have typical NOx emissions of 900 to 1500 ppm.

Limitations: Prechamber diesel engines are generally less fuel efficient than direct injection diesel engines. This fuel penalty is roughly 5 to 10 percent. Retrofit parts to convert direct injection engines are generally not available. Thus, the use of this technique generally requires replacement of the engine.

When a prechamber diesel engine uses injection timing retard, the NOx reduction is not as great as when retard is used on a direct injection diesel. The prechamber design effectively retards timing, and the first several degrees of timing retard are the most effective. For a direct injection diesel, NOx emissions are reduced by about 4 to 6 percent for every degree of retard, while for a prechamber diesel the NOx reduction is about one percent for every degree of retard.

Other Effects: Emissions of VOC, CO, and particulate matter tend to be lower for prechamber diesel engines than for direct injection engines.

Costs: There should be no significant cost difference between a new prechamber diesel engine and a new direct injection diesel engine. Retrofit costs to convert a direct injection engine to a prechamber diesel should be similar to the cost of replacing the heads of a natural gas engine with prechamber heads.

7. Prechamber Design (Dual Fuel Engines)

Applicability: The prechamber design head can also be used on dual fuel engines. Dual fuel engines are engines that burn two fuels (usually diesel and natural gas) simultaneously. Use of a prechamber on a dual fuel engine, however, is slightly different compared to engines using diesel exclusively. Several manufacturers of dual fuel engines now offer prechamber designs for their new engines, and also offer prechamber retrofit kits for some of their older dual fuel engines.

Principle: A dual fuel engine's operation is similar to that of a conventional diesel engine, with diesel fuel being injected into the combustion chamber to initiate combustion. In a dual fuel engine, however, supplemental fuel is added to the intake air (or, in a few cases, is injected directly into the combustion chamber). In most applications, the amount of diesel used is a constant, and supplemental fuel is introduced as power requirements increase. At idle, a dual fuel engine operates on 100 percent diesel fuel, while at full power a direct injection dual fuel engine uses about 5 percent diesel. However, for prechamber engines, diesel use can drop to as low as one percent at full power. Although in most applications the use of supplemental fuel is maximized, most dual fuel engines can generate full power on diesel fuel alone. Dual fuel engines typically operate on diesel fuel exclusively only when supplemental fuel is not available.

The dual fuel engine is inherently low in NOx emissions because only a small amount of diesel is used and the natural gas is combusted as a very lean mixture. Prechamber dual fuel engines are lower still in NOx emissions, as they can burn an even leaner natural gas mixture and use even less diesel.

Typical Effectiveness: NOx emissions are typically between 400 and 800 ppm for a conventional uncontrolled dual fuel engine, and less than 90 ppm for a new low NOx prechamber dual fuel engine.

Limitations: Retrofit kits may not be available for older dual fuel engines. Dual fuel engines are often used where a natural gas engine would ordinarily be used, except the supply of natural gas is subject to curtailment. If the natural gas is curtailed, most dual fuel engines can switch to diesel fuel exclusively and still generate full power. When operated on diesel exclusively, emissions from a dual fuel engine are comparable to a diesel engine of similar design, and NOx emissions increase substantially.

Other Effects: Emissions of other pollutants are comparable between dual fuel engines and natural gas engines.

Costs: The cost of a prechamber retrofit should be similar to the cost of a prechamber retrofit for a diesel or natural gas-fired engine.

8. <u>Ceramic Coatings</u>

Applicability: This technique can be applied to all engines, although for purposes of emission reductions the technique has been applied primarily to CI (diesel) engines. The following discussion deals exclusively with the application of ceramic coatings on CI engines. Ceramic coatings have been used for more than five years, and have been applied to a number of different engines. However, as of a year ago, only a few hundred engines have used this technique. Ceramic coatings may see greater use in the future due to thermal efficiency improvements associated with this technique. The popularity of this technique may also improve because ceramic coatings can help mobile and stationary diesel engines to meet more effective future emission limits.

Principle: This technique consists of applying a ceramic thermal barrier coating to combustion chambers, valve faces, and the tops of pistons. The coating insulates the combustion system components from heat and thermal shock, protects metal components against high temperature corrosion, reduces component temperatures and thermal fatigue. The insulation properties allow more of the heat from combustion to be converted into useful energy.

By retaining heat in the combustion chamber, ceramic coatings reduce ignition delay (i.e., the time between the start of fuel injection and ignition of the fuel). Reduced ignition delay spreads combustion over a longer period of time, which reduces peak temperatures (thereby reducing NOx formation) and results in more complete combustion. The improvements in combustion result in lower VOC, CO, and particulate matter emissions. This technique has been used primarily to improve engine efficiency and reduce exhaust opacity. Although impacts on NOx emissions are minimal, the use of thermal barrier coatings can be combined with other control techniques such as injection timing retard and an oxidation catalyst to simultaneously reduce NOx, VOC, CO, and particulate matter emissions without increasing fuel consumption or reducing maximum power.

Typical Effectiveness: Use of ceramic coatings on diesel engines has resulted in a

50 percent reduction in opacity and a 30 percent reduction in particulate matter emissions. NOx reductions are limited to a few percent if this technique is used alone. If used in conjunction with other NOx control techniques, the effectiveness of these other techniques can be maximized. With a combination of methods, such as ceramic coatings, injection timing retard, and oxidation catalyst, NOx emission reductions of 40 to 60 percent are possible for diesel engines, along with reductions in VOC, CO, and particulate matter.

Application of this technique to engines other than diesels has been primarily for improvements in engine efficiency rather than for emission reduction purposes. Thus, its effectiveness in reducing emissions for engines other than diesel is less clear.

Limitations: Although this technique can be easily applied to new engines, costs for retrofits can be relatively high unless the ceramic coating is applied during a major engine rebuild. The NOx reductions associated with this method are minor unless used in conjunction with other techniques.

Other Effects: Thermal barrier coatings tend to decrease fuel consumption, increase engine life, increase power output, reduce cetane number requirements, reduce engine noise, and increase cold start reliability at low temperatures. One 4-year on-road demonstration of this technique noted a seven percent improvement in fuel economy, with no wear or deterioration of the engine coating after over 100,000 miles of operation.

Costs: Costs are about $1,000 to treat the cylinder heads, valve heads, and piston tops of a 6V92TA Detroit Diesel bus engine, with discounts on this price for the coating of a fleet of engines. To treat a single 9 inch diameter piston, the cost is about $400. Pistons up to 30 inches in diameter have been treated. Total costs, including disassembly and reassembly of the engine, are about $5 to $12 per horsepower. This technique is reported, in most cases, to pay for itself in reduced fuel and maintenance costs.

9. Modified Injectors

Applicability: This technique refers to several changes to the conventional injector system used on diesel engines. All of these changes have been widely used on a number of engines.

Principle: There are several modifications that can be made to standard fuel injectors that will reduce emissions. Standard injectors can be replaced with electronically controlled injectors, which allow more flexibility in adjusting timing for various operational modes. With this added flexibility, timing can be retarded further in certain modes where operational problems are not encountered, and less in other modes where such problems are encountered. In this fashion, NOx emissions can be minimized while also minimizing the adverse effects from retarding injection timing.

Another injector modification is an improved injector nozzle. Improved nozzles provide a finer, more uniform spray pattern which promotes greater mixing of the air and fuel. This improved pattern tends to reduce VOC, CO, and particulate matter emissions, while also reducing NOx emissions to a minor degree. The improved nozzles allow the use of injection timing retard, or greater amounts of retard, without encountering operational problems.

Other injector modifications include high pressure injectors. Higher pressures improve the atomization and mixing of the fuel with air, increasing the burn rate and thereby reducing emissions of particulate matter and VOC. In addition, the injection process will take less time, allowing the injection to start later in the engine cycle and end earlier. Starting the injection later is effectively the same as retarding the injection timing, which can reduce NOx emissions significantly. Shortening the injection duration also tends to increase engine efficiency.

Typical Effectiveness: NOx reductions from this technique are minimal unless combined with other control methods. When used in conjunction with other techniques such as injection timing retard, NOx reductions can reach 50 percent without adversely affecting particulate matter emissions. The effectiveness of this method for the control of CO, VOC, and particulate matter vary with the application.

Limitations: Retrofit parts are not available for all makes and models of diesel engines, especially older engines. In some cases, retrofit parts may be available only for diesel engines that are derivatives of recent on-road truck engines.

Other Effects: Shortening the injection duration tends to increase engine efficiency.

Costs: The cost of electronic controls for on-road trucks is about $4,000. However, this cost includes a full electronic system that controls operation of the engine, transmission, and other components. Electronic controls designed exclusively to operate the fuel injectors (which would be the only electronic controls necessary for stationary engines) are less costly. Costs for finer spray injectors and higher pressure injection systems should be comparable or less costly than the cost of electronic controls.

10. Optimization of Internal Engine Design

Applicability: This control method applies to all new engines and is widely used, although the following discussion applies primarily to diesel engines.

Principle: Proper design of such parts as the intake manifold, ports, combustion chamber, and injectors, along with steps to minimizing oil consumption, can reduce VOC, particulate matter, and CO emissions. This allows the use, or increased use, of some NOx control methods without increasing emissions of other pollutants to an undesirable level.

For example, higher injection pressures will increase penetration of the diesel fuel into the combustion air, resulting in good mixing and reduced CO, particulate matter, and VOC emissions. However, if penetration is excessive, fuel could impinge on cylinder walls. To avoid impingement, the incoming air charge can be swirled into the combustion chamber, which deflects the fuel away from the cylinder walls. On the other hand, too much deflection can result in a lack of penetration of the fuel, which will tend to increase VOC and particulate matter emissions. To minimize emissions, the intake manifold and ports must be designed to provide an optimal amount of swirl for a given engine design and fuel injection pressure.

On many diesel engines, the combustion chamber consists of a bowl formed in the piston top. Improved bowls are shaped so that vortices of swirling air are generated during the compression stroke, which assist mixing. Proper design of this bowl will result in more rapid burning, more complete combustion, and reduced VOC and particulate matter emissions.

Piston rings and pistons can be redesigned so that the top piston ring is closer to the top of the piston, which reduces the volume of combustion air and fuel trapped between the piston and cylinder wall. This trapped volume does not combust, so any reduction in this volume will reduce VOC emissions.

A higher compression ratio can be used, which will tend to reduce ignition delay and allow the use of more injection timing retard to control NOx emissions. A higher compression ratio will also reduce particulate matter and VOC emissions.

A significant portion of diesel engine particulate matter emissions comes from lube oil consumption. Improvements in the design, materials, and machining of the piston ring and cylinder bore can reduce oil consumption and consequently reduce particulate matter emissions.

Typical Effectiveness: The effectiveness of these methods vary with the initial engine design and degree of changes made. For on-road truck engines, a combination of these methods

and others, such as injection timing retard, turbocharging, and aftercoolers, has allowed on-road truck engines to meet stringent emission limits.

Limitations: Many new engines have already been optimized to some extent, so further emission reduction opportunities will be minimal for these engines. Retrofit of many of the optimization techniques may not be feasible for older engines. Some methods could have undesirable side effects if not optimized properly. For example, care must be taken when using methods to reduce oil consumption to assure that engine wear is not adversely affected.

Other Effects: None known.

Costs: Increased costs to manufacture the hardware are minimal; however, research and development costs for the hardware can be significant.

11. Turbocharging or Supercharging and Aftercooling

Applicability: This control method can be used on almost any engine and is widely used.

Principle: Turbochargers and superchargers compress the intake air of an engine before this air enters the combustion chamber. Due to compression, the temperature of this air is increased. This tends to increase peak temperatures, which increases the formation of NOx. However, the heat sink effect of the additional air in the cylinder, combined with the increased engine efficiency from turbocharging or supercharging, generally results in a minor overall decrease in NOx emissions per unit of power output. On the other hand, turbocharging or supercharging can significantly increase the maximum power rating of an engine, which increases the maximum mass emissions rate for NOx. Due to the high density of oxygen in the combustion chamber, turbocharging or supercharging makes the combustion process more effective, which tends to reduce emissions of CO, VOC, and especially particulate matter for diesel engines.

On turbocharged or supercharged engines, the intake air temperature can be reduced by aftercooling (also known as intercooling or charge air cooling). An aftercooler consists of a heat exchanger located between the turbocharger or supercharger and combustion chamber. The heat exchanger reduces the temperature of the intake air after it has been compressed by the supercharger or turbocharger. Cooling the intake air reduces peak combustion temperatures, and thereby reduces NOx emissions. The cooling medium can be water, either from the radiator or from a source outside of the engine, or the cooling medium can be ambient air. The use of radiator water generally results in the least amount of cooling, while the use of outside water or ambient air results in the most cooling of the intake air. Without aftercooling, the air entering the combustion chambers of a turbocharged or supercharged diesel engine will have a temperature typically about 350 degrees F (^{o}F). Using a radiator water aftercooler will reduce this temperature to about 210

°F. Using either a cooler source of water or ambient air for the aftercooler can reduce the intake air temperature to as low as 90 °F.

The cooling effects of the aftercooler increases the density of the intake air, which results in a leaner air/fuel mixture in SI engines if no additional fuel is introduced. For engines already using lean air/fuel mixtures, this leaner mixture will lower NOx emissions further.

Typical Effectiveness: NOx reductions from aftercooling range from about 3 to 35 percent. The percentage reduction is roughly proportional to the reduction in temperature. Particulate matter emission reductions from turbocharging or supercharging a diesel engine are significant, but it is difficult to quantify this reduction. Reductions in VOC and CO emissions also occur, but are generally less than the effect on particulate matter emissions.

Limitations: Turbochargers or superchargers may not be available for some engines. In addition, some internal engine parts may have to be replaced or strengthened when adding a supercharger or turbocharger.

Other Effects: Use of a supercharger or turbocharger increases the efficiency and maximum power rating of an engine. Use of an aftercooler further increases the efficiency of an engine, and can also increase the maximum power rating. At low loads and excessive temperature reductions, an aftercooler can cause longer ignition delays, which increase emissions of VOC and particulate matter. This emissions increase can be minimized if an aftercooler bypass is used to limit cooling at low loads.

Costs: The cost of retrofitting a naturally aspirated engine with a turbocharger and related equipment varies from engine to engine. These costs vary not only because different sizes of turbochargers are used for different engines, but also because different engines may require more extensive internal modifications.

The cost is about $2,400 to retrofit a Detroit Diesel 6V53 with an aftercooler, matching turbo, and crankcase vent. The cost is about $8,000 to convert a Detroit Diesel 8V71 naturally aspirated engine into a turbocharged, aftercooled version of this engine. To upgrade an older Detroit Diesel 8V92TA (which already has a turbocharger and aftercooler) to match the NOx performance of the latest version of the 8V92TA costs about $9,000.

For natural gas engines, costs of a turbocharger retrofit are typically $30,000 to $40,000 for engines in the 800 to 900 horsepower range. For natural gas engines in the 1,100 to 1,300 horsepower range, costs can vary from $35,000 to $150,000.

In some cases, replacement of an existing engine with a new, low NOx emitting turbocharged engine may result in lower overall costs than retrofitting the existing engine with a turbocharger or supercharger. Although the capital cost of the new engine will generally be greater than the retrofit cost for the existing engine, the new engine will reduce overall costs due to increased efficiency, reduced down time, and reduced maintenance and repair costs.

Except in cases where an engine's usage factor is very low, the improved fuel efficiency associated with the use of turbochargers, superchargers, and aftercoolers generally results in a cost savings.

12. <u>Exhaust Gas Recirculation</u>

Applicability: Exhaust gas recirculation, or EGR, can be used on all engine types. It has been widely used on gasoline and diesel motor vehicle engines, but has been used infrequently on engines used in other applications.

Principle: EGR can be external or internal. In the case of external EGR, a portion of the exhaust gas is diverted from the exhaust manifold and routed to the intake manifold before reentering the combustion chamber. For internal EGR, an engine's operating parameters (such as valve timing or supercharger pressure) are adjusted so that a greater amount of exhaust remains in the cylinder after the exhaust stroke.

EGR reduces NOx emissions by decreasing peak combustion temperatures through two mechanisms: dilution and increased heat absorption. Dilution of the fuel/air mixture slows the combustion process, thereby reducing peak temperatures. In addition, exhaust gases contain significant amounts of carbon dioxide and water vapor, which have a higher heat capacity than air. This means that, compared to air, carbon dioxide and water vapor can absorb greater amounts of heat without increasing as much in temperature.

Typical Effectiveness: NOx reductions are limited to about 30 percent before operation of the engine is adversely affected.

Limitations: EGR will reduce an engine's peak power. This may be a serious problem for engines required to operate at or near their peak power rating. The EGR system must be designed and developed for each make and model of engine. An EGR retrofit kit is not available for most engines. Another potential limitation with this technology is that, when applied to diesel engines, smoke emissions increase. For some applications on large diesel engines, the exhaust may have to be cooled first before being injected into the intake manifold. In addition, since the diesel exhaust, containing a high concentration of particulate matter, must be introduced into the turbocharger, the turbocharger and aftercooler may experience fouling problems. The use of clean diesel fuel or a particulate trap may be required to avoid clogging problems. EGR on diesel engines also will increase engine wear, due to the presence of particulate matter in the exhaust.

Other Effects: EGR reduces engine efficiency. For example, fuel efficiency decreases about 2 percent for a 12 percent decrease in NOx emissions.

Costs: Costs are typically greater than for timing retard, but less than a turbocharger retrofit.

13. <u>Prestratified Charge</u>

Applicability: This control method is applicable to spark-ignited rich-burn engines. This method converts rich-burn engines into lean burn engines. It has been used on a number of different engines, but is not as widely used as some of the most popular controls, such as clean burn or NSCR catalysts.

Principle: Rich-burn engines are typically four stroke naturally aspirated engines with no intake/exhaust overlap. The major components of a prestratified charge (PSC) retrofit are the air injectors. These injectors pulse air into the intake manifold in such a fashion that layers or zones of air and the air/fuel mixture are introduced into the combustion chamber. Once inside the combustion chamber, the top zone, near the spark plug, contains a rich air/fuel mixture. The bottom zone is an air layer. The most recent version of the PSC system operates off of engine vacuum, which allows the system to automatically compensate for varying power outputs.

The PSC technique is very similar in concept to a precombustion chamber. Both have a rich fuel mixture near the spark plug, and a lean mixture elsewhere in the combustion chamber. NOx emissions are low for PSC for the same reasons they are low for prechamber designs.

Typical Effectiveness: PSC can achieve greater than 80 percent control of NOx for power outputs up to about 70 or 80 percent of the maximum (uncontrolled) power rating using air injection only.

Limitations: In order for the engine to generate more than 70 or 80 percent of the maximum (uncontrolled) power rating, the air injection rate must be reduced. This results in a richer fuel mixture, which increases NOx emissions. To maintain high NOx control at high power outputs, a turbocharger may have to be added or the existing turbocharger may have to be modified or replaced to increase air throughput. Maximum emission reductions, even with use of a turbocharger, are generally lower than can be accomplished with the use of an NSCR catalyst.

Other Effects: Fuel efficiency may be improved because PSC effectively converts a rich-burn engine into a lean-burn engine.

Costs: For engines in the 300 to 900 horsepower range, retrofit costs are typically about $30,000. For engines in the 1100 to 1600 horsepower range, retrofit costs are about $40,000. However, costs can double if a turbocharger is added. Retrofits for even larger engines where a turbocharger is added can cost as much as $160,000 to $190,000.

B. Fuel Switching

NOx emissions from IC engines can be reduced by switching to fuels that burn at lower temperatures. These fuels include water/fuel mixtures, methanol, and clean diesel.

1. Water/Fuel Mixtures

Applicability: This control method can be used on any engine, but has been applied mostly to diesel engines. Only a few commercial retrofits have occurred. However, several engine manufacturers have recently offered such systems as options on their new engines.

Principle: Water vapor acts as a heat sink to reduce peak temperatures, thereby reducing NOx formation. In most cases, the water is injected into the intake manifold or is mixed with diesel fuel to form a water/fuel emulsion. In the case of emulsions, the engine's fuel injectors inject the emulsion directly into the combustion chambers. One manufacturer, Wartsilla, uses separate injectors to inject water directly into the combustion chambers of some of their diesel engines. Mitsubishi has developed a variation of this method called stratified fuel-water injection. Water is introduced into the fuel injector in pulses such that, during each injection episode, fuel is injected into the combustion chamber first, followed by water. One company uses a water/naphtha mixture as a substitute for diesel.

Typical Effectiveness: NOx reductions are roughly proportional to the amount of water used. Water/fuel emulsions allow a greater amount of water to be used than if the water is injected into the intake manifold. NOx reductions up to about 35 percent are possible by introducing water into the intake manifold, and up to about 60 percent for water/fuel emulsions or direct injection of water into the combustion chamber. For the Mitsubishi system, NOx reductions of about 60 percent are possible with a water/fuel ratio of 0.5:1.

Limitations: Existing diesel engines must be retrofitted with larger injectors when using this fuel type. Engine operation can be adversely affected if the water/fuel ratio is too high. In addition, this method can have reliability problems with the water system and engine. Specifically, there can be corrosion from the water's action on engine parts, breakdown of motor oil by dilution with water, engine deposits from impurities dissolved in the water, and, for emulsions of water and diesel, separation of the water and diesel fuel. The deposit problem can be minimized by using extremely pure water, while the separation problem can be minimized by emulsifying the water and fuel immediately before injection into the engine or by using an emulsifying agent.

Other effects: None known.

Costs: Unknown.

2. Methanol

Applicability: This control method is applicable to all engine types. Although a number of motor vehicle engines have been converted to methanol fuel, very few stationary source engine conversions have taken place.

Principle: NOx emissions are generally lower for methanol than for other fuels for several reasons. Methanol has a higher heat of vaporization than other fuels, and thus the process of vaporization cools the air/fuel mixture significantly, resulting in lower peak temperatures. Methanol, being a partially oxygenated fuel, burns with a lower flame temperature, which also reduces peak temperatures. Methanol fuel consists of only one type of molecule, which makes it easier to optimize the combustion process in comparison to fuels consisting of a wide variety of molecules, such as gasoline or diesel. Compared to diesel fuel, methanol combustion produces almost no particulate matter.

For rich-burn methanol engines, a relatively inexpensive three-way catalyst like that used in gasoline-engined motor vehicles can be installed to control NOx. Methanol can also be used as a fuel for lean-burn spark-ignited engines. Methanol has a wider range of flammability than many other fuels, allowing a leaner mixture to be used, resulting in greater NOx reductions than is possible with other fuels.

Methanol can be used as a replacement fuel for gaseous and gasoline fueled engines with only relatively minor engine modifications. Conversion of diesel engines to methanol, however, requires more extensive engine modifications. These modifications include oversized injectors and pumps. In addition, to improve combustion to an acceptable level, either the compression ratio of the engine must be increased, cetane improvers must be added to the methanol, or spark plugs must be installed in the cylinder head.

Typical Effectiveness: NOx reductions from the conversion of an engine to methanol fuel depend on the pre-conversion engine and fuel type. NOx reductions range from about 30 percent for the conversion of a natural gas engine to about 80 percent for a diesel engine conversion. Reductions are even greater when the conversion is accompanied by the addition of a catalyst.

Limitations: A retrofit kit must be developed for each make and model of engine. Currently, there are very few conversion kits available. The fuel and engine system must use materials that are resistant to the corrosive action of methanol. Special lubricants must be used to avoid excessive engine wear. Incomplete combustion of methanol produces formaldehyde, but the use of an oxidation catalyst can reduce formaldehyde emissions to low levels.

Other Effects: The conversion of a diesel engine to methanol will greatly reduce particulate matter emissions.

Costs: Conversion costs for an automotive engine are on the order of $1,000. Costs for converting stationary gasoline engines to methanol are expected to be similar. For diesel engines, where modifications are more extensive, costs are typically several thousand dollars, and may approach $10,000. The largest cost element is often is the fuel price differential between methanol and the fuel it replaces (e.g., natural gas, gasoline or diesel). Included in this price differential are transportation, storage, and refueling costs associated with the use of methanol.

3. <u>Clean Diesel Fuel</u>

Applicability: This control method is only applicable to diesel engines. Nearly all diesel engines in California currently use this type of fuel, thus this control method is in widespread use.

Principle: "Clean" diesel fuel is diesel fuel for on-road motor vehicles that meets ARB regulations regarding sulfur and aromatic content. These regulations were adopted in 1988 and became effective in 1993. The regulations limit sulfur content to 0.05 percent by weight and aromatic hydrocarbon content to 10 percent by volume. These regulations allow use of an alternative diesel fuel formulation with an aromatic hydrocarbon content higher than 10 percent, if it is demonstrated that emissions benefits from the alternative formulation are equivalent or greater than the benefits from fuel meeting the 10 percent aromatics limit. Clean diesel is lower in sulfur and aromatic hydrocarbon content than normal diesel fuel, and generally has a higher cetane number. The cetane and aromatic hydrocarbon characteristics of clean diesel tend to reduce ignition delay, which reduces peak temperatures and NOx emissions. The higher cetane number and the lower sulfur and aromatics content also tend to reduce particulate matter emissions.

Typical Effectiveness: The overall average NOx reduction from the use of clean diesel fuel is about 7 percent when compared to normal diesel fuel. The reduction in SO_2 emissions is about 82 percent, while the particulate matter less than 10 micrometers in aerodynamic diameter (PM10) reduction is about 25 percent.

Limitations: None known.

Other Effects: In an extremely small number of cases, some types of seals found on older engines may fail prematurely. No problems have been encountered with updated replacement seals.

Costs: The average additional cost for refining clean diesel fuel is about one to four cents per gallon. The wholesale price of clean diesel has averaged about two to four cents per gallon more than conventional diesel sold in neighboring states.

C. Post Combustion Controls

Post combustion controls generally consist of catalysts or filters that act on the engine exhaust to reduce emissions. Post combustion controls also include the introduction of agents or other substances that act on the exhaust to reduce emissions, with or without the assistance of catalysts or filters.

1. Oxidation Catalyst

Applicability: This control method is applicable to all engines. For stationary engines, oxidation catalysts have been used primarily on lean-burn engines. Rich-burn engines tend to use 3-way catalysts, which combine nonselective catalytic reduction (NSCR) for NOx control and an oxidation catalyst for control of CO and VOC. The oxidation catalyst has been used on lean-burn engines for nearly 30 years. In 1994 alone, 350,000 new diesel engined vehicles were built which used oxidation catalysts. Oxidation catalysts are used less frequently on stationary engines. Only about 500 stationary lean-burn engines have been fitted with oxidation catalysts, and only 150 of these lean-burn engines have been diesel engines. Besides CO and VOC, oxidation catalysts can also reduce particulate matter emissions from diesel engines. This reduction appears to be limited to the soluble organic fraction of the particulate matter, with no reduction in the dry soot (carbon) fraction of diesel particulate matter emissions.

Oxidation catalysts are often retrofitted to engines that use combustion modifications to control NOx. These combustion modifications often increase emissions of pollutants other than

NOx, and the use of the oxidation catalyst in conjunction with the combustion modifications can result in an overall reduction in emissions of particulate matter, NOx, CO, and VOC.

Principle: An oxidation catalyst contains materials (generally precious metals such as platinum or palladium) that promote oxidation reactions between oxygen and CO, VOC, or particulate matter to produce carbon dioxide and water vapor. These reactions occur when exhaust at the proper temperature and containing sufficient oxygen passes through the catalyst. Depending on the catalyst formulation, an oxidation catalyst may obtain reductions at temperatures as low as 300 or 400 ^{o}F, although minimum temperatures in the 600 to 700 ^{o}F range are generally required to achieve maximum reductions. The catalyst will maintain adequate performance at temperatures typically as high as 1350 ^{o}F before problems with physical degradation of the catalyst occur. In the case of rich-burn engines, where the exhaust does not contain enough oxygen to fully oxidize the CO and VOC in the exhaust, air can be injected into the exhaust upstream of the catalyst.

Typical Effectiveness: The effectiveness of an oxidation catalyst is a function of the exhaust temperature, oxygen content of the exhaust, amount of active material in the catalyst, flow rate through the catalyst, and other parameters. Catalysts can be designed to achieve almost any control efficiency desired. Reductions greater than 90 percent for both CO and VOC are typical. Reductions in VOC emissions can vary significantly and are a function of the fuel type and exhaust temperature. Efficiencies for diesel engines tend to be lower, with CO reductions of 40 to 90 percent and VOC reductions of 30 to 80 percent being reported as typical.

Oxidation catalysts can reduce particulate matter emissions from diesel engines by 30 to 50 percent, depending on the composition of the particulate matter. This reduction may not be as great when an oxidation catalyst is combined with other particulate matter reduction methods or if the engine is inherently low in particulate matter emissions. One study found particulate matter emissions from diesel engines were reduced by 30 percent through the use of ceramic coatings alone. This reduction increased to only 35 percent when an oxidation catalyst was added. In a Los Angeles bus engine rebuilding program, rebuild kits designed to minimize particulate matter emissions were installed in conjunction with oxidation catalysts. This program reduced particulate matter emissions by only 25 percent.

Limitations: A sufficient amount of oxygen must be present in the exhaust for the catalyst to operate effectively. In addition, the effectiveness of an oxidation catalyst may be poor if the exhaust temperature is low, which is the case for an engine at idle. Oxidation catalysts, like other catalyst types, can be degraded by masking, thermal sintering, or chemical poisoning by sulfur or metals. If the engine is not in good condition, a complete engine overhaul may be needed to ensure proper catalyst performance.

Sulfur, which can be found in fuels and lubricating oils, is generally a temporary poison, and can be removed by operating the catalyst at a sufficiently high temperatures. Other ways of dealing with sulfur poisoning include the use of low sulfur fuels or scrubbing of the fuel to remove the sulfur. Besides being a catalyst poison, sulfur can also be converted into sulfates by the catalyst before passing out the exhaust pipe. This conversion increases particulate matter emissions. Catalysts can be specially formulated to minimize this conversion, but these special formulations must operate over a relatively narrow temperature range if they are to effectively reduce VOC and CO and also suppress the formation of sulfates. For engines operated over wide power ranges where exhaust temperatures vary greatly, special catalyst formulations are not effective.

Metal poisoning is generally more permanent, and can result from the metals present in either the fuel or lubricating oil. Specially formulated oils with low metals content are generally specified to minimize poisoning, along with good engine maintenance practices. Metal poisoning can be reversed in some cases with special procedures. Many catalysts now are formulated to resist poisoning.

Masking refers to the covering and plugging of a catalyst's active material by solid contaminants in the exhaust. Cleaning of the catalyst can remove these contaminants, which usually restores catalytic activity. Masking is generally limited to engines using landfill gas, diesel fuel, or heavy liquid fuels, although sulfate ash from lubricating oil may also cause masking. Masking can be minimized by passing the exhaust through a particulate control device, such as a filter or trap, before this material encounters the catalyst. In the case of landfill gas, the particulate control device can act directly on the fuel before introduction into the engine. In addition, in the case of diesel engines, the use of low sulfur fuel, turbocharging, and engine combustion modifications can reduce the formation of particulate matter sufficiently to eliminate masking problems.

Thermal sintering is caused by excessive heat and is not reversible. However, it can be avoided by incorporating over temperature control in the catalyst system. Many manufacturers recommend the use of over temperature monitoring and control for their catalyst systems. In addition, stabilizers such as CeO_2 or La_2O_3 are often included in the catalyst formulation to minimize sintering. High temperature catalysts have been developed which can withstand temperatures exceeding 1800 ^oF for some applications. This temperature is well above the highest IC engine exhaust temperature that would ever be encountered. Depending on the design and operation, peak exhaust temperatures for IC engines range from 550 to 1300 ^oF.

Other recommendations to minimize catalyst problems include monitoring the pressure drop across the catalyst, the use of special lubricating oil to prevent poisoning, periodic washing of the catalyst, the monitoring of emissions, and the periodic laboratory analysis of a sample of catalyst material.

Other Effects: A catalyst will increase backpressure in the exhaust, resulting in a slight reduction in engine efficiency and maximum rated power. However, when conditions require an exhaust silencer, the catalyst can often be designed to do an acceptable job of noise suppression so that a separate muffler is not required. Under such circumstances, backpressure from the catalyst may not exceed that of a muffler, and no reduction in engine efficiency or power occur. Often, engine manufacturers rate their engines at a given backpressure, and as long as the catalyst does not exceed this backpressure no reduction in the engine's maximum power rating will be experienced.

Costs: Typical costs for an oxidation catalyst are 9 to 10 dollars per horsepower, or slightly less than a nonselective catalytic reduction (NSCR) catalyst. The cost for catalyst wash service has been reported as $300 to $600 per cubic foot of catalyst material.

2. Nonselective Catalytic Reduction (NSCR)

Applicability: This control method is applicable to all rich-burn engines, and is probably the most popular control method for rich-burn engines. The first wide scale application of NSCR technology occurred in the mid- to late-1970s, when 3-way NSCR catalysts were applied to gasoline-engined motor vehicles. Since then, this control method has found widespread use on stationary engines. NSCR catalysts have been commercially available for stationary engines for over 15 years, and over 3,000 stationary engines in the U.S. are now equipped with NSCR controls. Improved NSCR catalysts, called 3-way catalysts because CO, VOC, and NOx are simultaneously controlled, have been commercially available for stationary engines for over 10 years. Over 1,000 stationary engines in the U.S. are now equipped with 3-way NSCR controls.

The dual bed NSCR catalyst is a variation of the 3-way catalyst. The dual bed contains a reducing bed to control NOx, followed by an oxidizing bed to control CO and VOC. Dual bed NSCR catalysts tend to be more effective than 3-way catalysts, but are also more expensive, and have not been applied to as many engines as 3-way catalysts. Improved 3-way catalysts can approach the control efficiencies of dual bed catalysts at a lower cost, and for this reason dual bed catalysts have lost popularity to 3-way catalysts.

Principle: The NSCR catalyst promotes the chemical reduction of NOx by CO and VOC to produce carbon dioxide, water vapor, and nitrogen. The 3-way NSCR catalyst also contains materials that promote the oxidation of VOC and CO to form carbon dioxide and water vapor. To control NOx, CO, and VOC simultaneously, 3-way catalysts must operate in a narrow air/fuel ratio band (15.9 to 16.1 for natural gas-fired engines) that is close to stoichiometric. An electronic controller, which includes an oxygen sensor and feedback mechanism, is often necessary to maintain the air/fuel ratio in this narrow band. At this air/fuel ratio, the oxygen concentration in the exhaust is low, while concentrations of VOC and CO are not excessive.

For dual bed catalysts, the engine is run slightly richer than for a 3-way catalyst. The first catalyst bed in a dual bed system reduces NOx. The exhaust then passes into a region where air is injected before entering the second (oxidation) catalyst bed. NOx reduction is optimized in comparison to a 3-way catalyst due to the higher CO and VOC concentrations and lower oxygen concentrations present in the first (reduction) catalyst bed. In the second (oxidation) bed, CO and VOC reductions are optimized due to the relatively high oxygen concentration present. Although the air/fuel ratio is still critical in a dual bed catalyst, optimal NOx reductions are achievable without controlling the air/fuel ratio as closely as in a 3-way catalyst.

Typical Effectiveness: Removal efficiencies for a 3-way catalyst are greater than 90 percent for NOx, greater than 80 percent for CO, and greater than 50 percent for VOC. Greater efficiencies, below 10 parts per million NOx, are possible through use of an improved catalyst containing a greater concentration of active catalyst materials, use of a larger catalyst to increase residence time, or through use of a more precise air/fuel ratio controller.

For dual bed catalysts, reductions of 98 percent for both NOx and CO are typical.

The previously mentioned reduction efficiencies for catalysts are achievable as long as the exhaust gases are within the catalyst temperature window, which is typically 700 to 1200 ^{o}F. For many engines, this temperature requirement is met at all times except during startup and idling.

The percentage reductions are essentially independent of other controls that reduce the NOx concentration upstream of the catalyst. Thus, a combination of combustion modifications and catalyst can achieve even greater reductions.

Limitations: As with oxidation catalysts, NSCR catalysts are subject to masking, thermal sintering, and chemical poisoning. In addition, NSCR is not effective in reducing NOx if the CO and VOC concentrations are too low. NSCR is also not effective in reducing NOx if significant concentrations of oxygen are present. In this latter case, the CO and VOC in the exhaust will preferentially react with the oxygen instead of the NOx. For this reason, NSCR is an effective NOx control method only for rich-burn engines.

When applying NSCR to an engine, the sulfur content of the fuel gas must be limited to about 800 ppm by weight. The sulfur content of natural gas and LPG is well below 800 ppm, but some oil field gases and waste gases exceed this level. Sulfur tends to collect on the catalyst, which causes deactivation. This is generally not a permanent condition, and can be reversed by introducing higher temperature exhaust into the catalyst or simply by heating the catalyst. Even if deactivation is not a problem, the water content of the fuel gas must be limited when significant amounts of sulfur are present to avoid deterioration and degradation of the catalyst from sulfuric acid vapor.

For dual bed catalysts, engine efficiency suffers slightly compared to a 3-way catalyst due to the richer operation of engines using dual bed catalysts.

In cases where an engine operates at idle for extended periods or is cyclically operated, attaining and maintaining the proper temperature may be difficult. In such cases, the catalyst system can be designed to maintain the proper temperature, or the catalyst can use materials that achieve high efficiencies at lower temperatures. For some cyclically operated engines, these design changes may be as simple as thermally insulating the exhaust pipe and catalyst.

Most of these limitations can be eliminated or minimized by proper design and maintenance. For example, if the sulfur content of the fuel is excessive, the fuel can be scrubbed to remove the sulfur, or the catalyst design or engine operation can be modified to minimize the deactivation effects of the sulfur. Poisoning from components in the lube oil can be eliminated by using specially formulated lube oils that do not contain such components. However, NSCR applications on landfill gas and digester gas have generally not been successful due to catalyst poisoning and plugging from impurities in the fuel.

Other Effects: A very low oxygen content in the exhaust must be present for NSCR to perform effectively. To achieve this low oxygen content generally requires richening of the mixture. This richening tends to increase CO and VOC emissions. However, use of a 3-way catalyst can reduce CO and VOC emissions to levels well below those associated with uncontrolled engines.

Another effect of NSCR is increased fuel consumption. This increase is very slight when compared to an uncontrolled rich-burn engine. However, when compared to a lean-burn engine, a rich-burn engine uses 5 to 12 percent more fuel for the same power output. If a rich-burn engine uses a dual bed catalyst, a further slight increase in fuel consumption is generally experienced.

Costs: The total installed cost of an NSCR system on an existing engine varies with the size of the engine. The catalyst will cost about 8 to 15 dollars per horsepower, while air/fuel ratio controllers vary in cost from about $3,500 to $7,000. Installation and labor costs generally range from $1,000 to $3,000. For an 80 horsepower engine, total costs for installation may range from $5,000 to $11,000. For an 1,100 horsepower engine, installed costs of $20,000 to $25,000 are typical.

3. Hybrid System

Applicability: This control method can be applied to all engines. This control method was conceived by Radian Corporation, and has been developed by AlliedSignal and Beaird Industries. There has been one field prototype demonstration in San Diego, and it appears that the system has been offered commercially. However, there are no commercial applications of this technique.

Principle: The hybrid system is a modification of the dual bed NSCR system. The hybrid system adds a burner in the engine exhaust between the engine and the dual bed catalysts. The burner is operated with an excess amount of fuel so that oxygen within the engine exhaust is almost completely consumed, and large amounts of CO are generated. The exhaust then passes through a heat exchanger to reduce temperatures before continuing on to a reducing catalyst. The NOx reduction efficiency of the reducing catalyst is extremely high due to the high CO concentration (the CO acts as a reducing agent to convert NOx into nitrogen gas. The exhaust next passes through another heat exchanger, and air is added before the exhaust passes through an oxidation catalyst. The oxidation catalyst is extremely efficient in reducing CO and VOC emissions due to the excess oxygen in the exhaust.

Typical Effectiveness: NOx concentrations as low as 3 to 4 ppm are achievable with this system. Concentrations of CO and VOC are typical of systems using oxidation catalysts.

Limitations: When the oxygen content of the engine's exhaust is high, such as for lean-burn engines, the burner must use a large amount of fuel to consume nearly all the oxygen and generate sufficient amounts of CO. Therefore, use of this method on lean-burn engines is only practical in cogeneration applications, where heat generated by the burner can be recovered and converted to useful energy.

Other Effects: For rich-burn engines, this method has a fuel penalty of about one to five percent. However, for lean-burn engines, the fuel penalty could be equal to the uncontrolled engine's fuel consumption.

Costs: Costs are several times greater than for a simple NSCR catalyst. Capital costs were reported in 1993 as $150,000 for a 470 brake horsepower engine.

4. Selective Catalytic Reduction (SCR)

Applicability: This method was patented in the U.S. in the 1950s, and there have been over 700 applications of SCR to combustion devices worldwide,. However, most of these applications are external combustion devices such as boilers. SCR systems for IC engines have been commercially available for a number of years, but there have only been a few dozen SCR retrofits of IC engines. SCR is applicable to all lean-burn engines, including diesel engines.

Principle: The exhaust of lean-burn engines contains high levels of oxygen and relatively low levels of VOC and CO, which would make an NSCR type of catalyst ineffective at reducing NOx. However, an SCR catalyst can be highly effective under these conditions. Oxygen is a necessary ingredient in the SCR NOx reduction equation, and SCR performs best when the oxygen level in the exhaust exceeds 2 to 3 percent.

Differing catalyst materials can be used in an SCR catalyst, depending on the exhaust gas temperature. Base metal catalysts are most effective at exhaust temperatures between 500 and 900 ^{o}F. Base metal catalysts generally contain titanium dioxide and vanadium pentoxide, although other metals such as tungsten or molybdenum are sometimes used. Zeolite catalysts are most effective at temperatures between 675 to over 1100 ^{o}F. Precious metal catalysts such as platinum and palladium are most effective at temperatures between 350 and 550 ^{o}F.

In SCR, ammonia (or, in some cases, urea) is injected in the exhaust upstream of the catalyst. The catalyst promotes the reaction of ammonia with NOx and oxygen in the exhaust, converting the reactants to water vapor and nitrogen gas. Ammonia injection can be controlled by the use of a NOx monitor in the exhaust downstream of the catalyst. A feedback loop from the monitor to the ammonia injector controls the amount injected, so that NOx reductions are maximized while emissions of ammonia are minimized. To eliminate the use of a costly NOx monitor, some applications use an alternative system that measures several engine parameters. Values for these parameters are then electronically converted into estimated NOx concentrations.

Typical Effectiveness: The NOx removal efficiency of SCR is typically above 80 percent when within the catalyst temperature window.

Limitations: SCR can only be used on lean burn engines. Relatively high capital costs make this method too expensive for smaller or infrequently operated engines.

Some SCR catalysts are susceptible to poisoning from metals or silicon oxides that may be found in the fuel or lubricating oil. Poisoning problems can be minimized by using specially formulated lubricating oils that do not contain the problem metals, the use of fuels with low metals or silicon oxides content, or the use of zeolite catalysts which are not as susceptible to poisoning.

If platinum or palladium is used as an active catalyst material, the sulfur content of the exhaust must be minimized to avoid poisoning of the catalyst. In addition, for all types of SCR catalysts, high sulfur fuels will result in high sulfur oxides in the exhaust. These sulfur compounds will react with the ammonia in the exhaust to form particulate matter that will either mask the catalyst or be released into the atmosphere. These problems can be minimized by using low sulfur fuel, a metal-based SCR system specially designed to minimize formation of these particulate matter compounds, or a zeolite catalyst.

Ammonia gas has an objectionable odor, is considered an air pollutant at low concentrations, becomes a health hazard at higher concentrations, and is explosive at still higher concentrations. Safety hazards can occur if the ammonia is spilled or there are leaks from ammonia storage vessels. These safety hazards can be minimized by taking proper safety precautions in the design, operation, and maintenance of the SCR system. Safety hazards can be substantially reduced by using aqueous ammonia or urea instead of anhydrous ammonia. If a concentrated aqueous solution of urea is used, the urea tank must be heated to avoid recrystallization of the urea. In addition, if too much ammonia is injected into the exhaust, excessive ammonia emissions may result. These emissions can be reduced to acceptable levels by monitoring and controlling the amount of ammonia injected into the exhaust.

Many diesel engines emit significant amounts of particulate matter, which can cause plugging of the catalyst. Plugging problems can be minimized by reducing particulate matter in the exhaust through use of clean diesel fuel, a particulate trap, or an oxidation catalyst in front of the SCR catalyst. Plugging can also be minimized if the catalyst is periodically cleaned, or if a zeolite catalyst is used, which tends to be self cleaning if operated at a high enough temperature.

SCR may also result in a slight increase in fuel consumption if the backpressure generated by the catalyst exceeds manufacturer's limits.

Other Effects: None known.

Costs: SCR is one of the higher cost control methods due to the capital cost for the catalyst, the added cost and complexity of using ammonia, and the instrumentation and controls needed to carefully monitor NOx emissions and meter the proper amount of ammonia. Estimated costs, however have been declining over the past several years. Currently, costs are estimated to be about $50 to $125 per horsepower.

Engines operated at a constant load may be able to eliminate the NOx monitor and feedback ammonia metering system. In such cases, proper instrumentation must be used to monitor ammonia and NOx when the SCR system is set up. Frequent checks are also needed to assure that the setup does not change. Such a system was purchased in 1996 for a 1,300 horsepower diesel engine at a cost of approximately $100,000.

5. Lean NOx Catalyst

Applicability: This control method can be used on any lean-burn engine, although development work has concentrated on diesel engines. This control method is still in the development stage and is not commercially available, but may be available in a few years.

Principle: A number of catalyst materials can be used in the formulation of lean NOx catalysts. The constituents are generally proprietary. NOx reductions are generally minimal unless a reducing agent (typically raw fuel) is injected upstream of the catalyst to increase catalyst performance to acceptable levels. Depending on the catalyst formulation, this method can reduce NOx, CO, and VOC simultaneously.

Typical Effectiveness: NOx control efficiencies have been relatively low for most of the catalyst systems tested.

Limitations: Use of a reducing agent increases costs, complexity, and fuel consumption. The reducing agent injection system must be carefully designed to minimize excess injection rates. Otherwise, emissions of VOC and particulate matter can increase to unacceptable levels. Tests have shown that lean NOx catalysts produce significant amounts of nitrous oxide (N_2O), and that this production increases with increasing NOx reduction efficiencies and reducing agent usage. This method is not commercially available, and is still in the development stage.

Other Effects: None known.

Costs: Since no systems have been sold commercially, costs are unknown, but would probably exceed those for NSCR.

6. Cyanuric Acid

Applicability: This control method, formerly known as RAPRENOX, is applicable to lean-burn engines. This technology is commercially available for diesel engines rated at 700 to 13,000 horsepower, and can also be applied to lean-burn gaseous fueled engines. This technology is relatively new, and there have only been a few commercial applications.

Principle: In this method, solid cyanuric acid ($(HNCO)_3$), upon heating, is converted into a gas. Further heating to 625 ^oF forms gaseous isocyanic acid (HNCO). The isocyanic acid is injected into the exhaust downstream of the turbocharger, along with a fuel such as propane or diesel. The fuel increases the exhaust temperature to a range of 1,150 to 1,450 ^oF, where reactions between nitric oxide (NO) and HNCO generate N_2, CO_2, and H_2O. To improve conversion efficiencies, the exhaust passes into a large insulated reaction chamber to increase the residence time at high temperature.

Typical Effectiveness: NOx emission reductions of 80 to 90 percent are typical, and the system can be designed to reduce NOx by well over 90 percent. For diesel engines, particulate matter can be reduced by 80 percent and VOC by 98 percent.

Limitations: Significant amounts of fuel are used to heat the exhaust. Although this technology may be economically attractive for cogeneration applications where the energy used to heat the exhaust is recovered, the economics are less favorable for applications where the exhaust heat is not recovered. This technology may not be economically attractive when an engine's power output remains below 50 percent of full power. At low power outputs, exhaust temperatures are low, and greater amounts of fuel must be used to achieve the required exhaust temperature. The size of the reaction chamber may make applications difficult where there is a lack of room.

Other Effects: None known.

Costs: For a 4,000 horsepower diesel engine operated at 50% of capacity, installed costs are $17.50 per horsepower, or $70,000. Annual operating costs include $115,500 for cyanic acid and $84,000 for additional fuel. In general, the capital costs for cyanic acid system are much lower than SCR, but operating costs are significantly higher.

7. Urea Injection

Applicability: This control method is applicable to all lean-burn engines. It has been used on several boilers to control NOx, but there have been no applications to internal combustion engines.

Principle: Urea injection is very similar to cyanuric acid injection, as both chemicals come in powder form, and both break down at similar temperatures to form compounds which react with nitric oxide. Differences are that a high temperature heating system is not required for urea injection. Instead, the urea is usually dissolved in water, and this solution is injected into the exhaust stream.

Typical Effectiveness: Unknown.

Limitations: The temperature window for urea is higher than the highest exhaust temperature of nearly all engines. Therefore, due to cost- effectiveness considerations, practical applications of urea injection are limited to engines in cogeneration applications. Specifically, these applications are limited to situations where supplemental firing is applied to the engine's exhaust to increase its temperature, and the exhaust heat is recovered and used.

Other Effects: Unknown.

Costs: Unknown.

8. <u>Diesel Particulate Filters</u>

Applicability: This method is applicable to diesel engines. There have been over 1,000 applications of this technology on mobile sources (primarily diesel buses), but only a few systems have been fitted to stationary diesel engines.

Principle: A filter is installed in the exhaust stream. The filter collects particulate matter while allowing the exhaust gases to pass through without creating excessive back pressure. Periodically, the particulate matter on the filter is burned or oxidized to regenerate or clean the filter to avoid excessive back pressure. Filter materials that have been used include ceramic monoliths, woven silica fiber coils, ceramic foam, mat-like ceramic fibers, wire mesh, and sintered metal substrates.

At high power outputs, the exhaust temperature is sufficient to oxidize the particulate matter collected on the filter without using any methods to enhance regeneration. However, many diesels operate at low power outputs for extended periods of time, resulting in exhaust temperatures too low to oxidize the particulate matter. Thus, in most applications, enhanced regeneration must be used.

Regeneration enhancement methods include those which reduce the temperature required for regeneration, increase the temperature of the exhaust, or periodically clean the filter. Methods that reduce required temperatures include coating the filter with a catalyst or use of special fuel additives. The fuel additives contain metals such as cerium, copper, or platinum, which become embedded in the particulate matter and serve as effective catalytic surfaces for oxidation. The fuel additives are formulated so that they do not adversely affect fuel quality or the engine's combustion process, and in some instances may improve combustion.

Regenerative methods that increase the temperature of the exhaust include direct heating of the exhaust by a burner or electric heater, throttling the air intake to one or more cylinders (which increases CO and HC emissions that, when oxidized at the filter, increases temperatures), throttling of the exhaust downstream of the filter, and the use of ceramic engine coatings on the combustion chamber, valves, and piston tops.

Regenerative methods involving cleaning generally consist of the use of compressed air flowing opposite to the exhaust flow. The particulate matter is then collected in a bag, where an electric heater is used to oxidize the particulate matter.

In some cases, two or more of the regenerative methods described previously are used together.

To guard against overheating of the particulate filter, some systems use a sensor that triggers an exhaust by-pass system when temperatures become excessive. Other systems use dual filters, with one filter collecting particulate matter while the other is being regenerated.

Particulate filters can be used in conjunction with other emission control techniques to either reduce particulate matter emissions or assure that such emissions do not increase due to the application of the other techniques. For example, a particulate filter can be used in conjunction with injection timing retard or exhaust gas recirculation to reduce particulate matter emissions increases associated with the use of these latter two control methods. In the case of exhaust gas recirculation, use of gases after they pass through the filter will reduce engine wear and fouling.

Typical Effectiveness: Collection efficiencies range from 50 to over 90 percent, depending on the design, but the more effective filters exceed 90 percent efficiency.

Limitations: Work is continuing to achieve high filtering efficiencies with low back pressure, improve the regenerative process, and improve the mechanical strength of the filter. Improved catalyst coatings have been developed which show promise, but are most effective on four-stroke engines rather than two-stroke engines due to the inherent higher exhaust temperatures associated with four-stroke engines. This technology has had limited application, and effective maintenance requirements are not well established. Some particulate filter systems have failed due to the lack of an effective maintenance program.

Residual, noncombustible particulate matter will build up on the filter, eventually increasing backpressure. Techniques must be used to remove this accumulated material.

Other Effects: The use of catalytic coatings on the filter will also reduce CO and VOC emissions.

Costs: Typical costs range from $30 to $50 per horsepower. The cost of replacing the particulate trap core for bus engines was reported to be $1,500 each in 1993, although this cost was projected to decrease to $500.

D. Replacement

Another method of reducing NOx is to replace the existing IC engine with an electric motor, or a new engine designed to emit very low concentrations of NOx. In some instances, the existing engine may be integral with a compressor or other gear, and replacement of the engine will require the replacement or modification of this other equipment as well.

Applicability: This control method is applicable to all engines.

Principle: Rather than applying controls to the existing engine, it is removed and replaced with either a new, low emissions engine or an electric motor.

Typical Effectiveness: New, low emissions engines can reduce NOx by 80 percent or more over uncontrolled engines. An electric motor essentially eliminates NOx emissions associated with the removed engine, although there may be minor increases in power plant emissions to supply electricity to the electric motor.

Limitations: In remote locations or where electrical infrastructure is inadequate, the costs of electrical power transportation and conditioning may be excessive. In cases where the existing engine operates equipment integral to the engines (such as some engine/compressors that share a common crankshaft), both the engine and integral equipment often must be replaced.

Other Effects: None known.

Costs: Costs of engine replacement are highly variable, and depend on the cost of electricity, whether transmission lines or power substations need to be built, useful remaining life for the existing engine, and other factors.

DRAFT

APPENDIX C

SUMMARY OF DISTRICT IC ENGINE RULES

ARB/SSD December 3, 1997

Following is a summary of all IC engine rules adopted by the districts in California.

South Coast Air Quality Management District
Rule 1110.1: Emissions from Stationary Internal Combustion Engines
(Adopted 10/26/84, Amended 10/4/85)

Applicability

>50 bhp, gaseous fueled engines only

Requirements and Standards

Rich-Burn	
NOx -	90% reduction, initial test, 80% reduction thereafter, or 90 ppm at 15% oxygen
CO -	2000 ppm at 15% oxygen
Lean-Burn	
NOx - General	80% reduction, initial test, 70% reduction thereafter, or 150 ppm at 15% oxygen
- Optional (combustion mods only)	2 grams per brake horsepower-hour

Exemptions

Agricultural operations
Emergency standby engines operation <200 hrs/yr
Firefighting and or flood control
LPG fueled
Research and Testing
Performance verification and testing
Engines operating in the Southeast Desert Air Basin portion of Los Angeles and Riverside Counties
Engines controlled under Rule 1110

South Coast Air Quality Management District
Rule 1110.1: Emissions from Stationary Internal Combustion Engines
(continued)

Administrative Requirements

Control Plan required by:

4/26/85 for all engines except those using sewage digester and landfill gas
4/26/86 for engines using sewage digester and landfill gas

Final Compliance*

	Compliance Date
>200 bhp engines in Los Angeles and Orange Counties	
Rich-Burn	
>500 bhp engines	12/31/85**
75% of 201-500 bhp engines	12/31/86**
Lean-Burn	
80% of >500 bhp engines	12/31/87
All other engines	12/31/95

*A 12 month delay was allowed in certain cases.
**Compliance date could have been deferred until 12/31/87 if total installed rated brake horsepower was 500 to 2000.

Monitoring Equipment

Rich-Burn
Vented exhaust gas NOx and CO concentrations, or air/fuel ratio setting for catalyst equipped engines

Lean-Burn
Vented exhaust gas NOx concentrations, and flow rate of reducing liquids or gases added to the exhaust gases in operation of catalyst NOx reduction systems

South Coast Air Quality Management District
Rule 1110.1: Emissions from Stationary Internal Combustion Engines
(continued)

Alternative Emission Control

Alternative Emission Control Plan which demonstrates equivalent emission reductions or, for basin-wide control plan, at least 5 percent greater emission reductions

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South Coast Air Quality Management District
Rule 1110.2: Emissions from Gaseous and Liquid-Fueled Internal Combustion Engines
(Adopted 8/3/90, Amended 9/7/90, 8/12/94, 12/9/94, 11/14/97)

Applicability

>50 bhp Stationary

Requirements and Standards

Permanently remove engine, replace engine with an electric motor, or reduce emissions to the following:

For engines that generate electric power, are fired on landfill gas or sewage digester gas, are used for pumping water(except aeration facilities), are fueled by field gas, are integral engine-compressors operating fewer that 4000 hrs per year, or are LPG-fueled:

Reference Limits at 15% oxygen on a dry basis:*

Pollutant	Engine Size	Reference Limit
NOx	≥500 bhp	36 ppm
	>50 and <500 bhp	45 ppm
VOC	All	250 ppm as methane

* Reference limits are converted to compliance limits by multiplying by engine efficiency and dividing by 25%. Engine efficiency is based on higher heating value (HHV) of fuel. Engines less than 25% efficient are treated as having an efficiency of 25%.

South Coast Air Quality Management District
Rule 1110.2: Emissions from Gaseous and Liquid-Fueled Internal Combustion Engines
(continued)

Compliance Limit at 15% oxygen on a dry basis:

CO 2000 ppm

For portable engines: meet limits equivalent to those in State portable engine registration program
For all other engines:

Compliance Limits at 15% oxygen on a dry basis:

NOx	36 ppm
VOC	250 ppm as methane
CO	2000 ppm

<u>Exemptions</u>

Agricultural operations
Emergency standby engines which operate fewer than 200 hours per year
Firefighting, flood control
Research and testing
Performance verification and testing
Engines located in some parts of Riverside County
Auxiliary engines used to power engines or gas turbines during start-up
Snow manufacturing or ski lift operation
Engines registered under the State portable engine program
Nonroad engines
Engines located on San Clemente Island

South Coast Air Quality Management District
Rule 1110.2: Emissions from Gaseous and Liquid-Fueled Internal Combustion Engines
(continued)

Administrative Requirements

Compliance Schedule

	Final Compliance Date
Replace with electric motor, remove engine, or meet limits of 0.15 gm/bhp-hr for NOx and VOC, 0.6 gm/bhp-hr for CO	12/31/99
Engines previously required to meet Rule 1110.1 limits	12/31/04
Portable engines	
- less effective standards	12/31/99
- more effective standards	12/31/09
Other Engines	12/31/94

Monitoring and Recordkeeping

Engines >1000 bhp and >2 million bhp-hr per year must use continuous emissions monitoring for NOx.
Monitoring system shall have data gathering and retrieval capability
Operational non-resettable totalizing time meter required
Source testing of NOx, VOC, and CO every 3 years
Maintain operating log

Test Methods

NOx EPA Method 20 or District Method 100.1
CO EPA Method 10 or District Method 100.1
VOC EPA Method 25 or District Method 25.1

Santa Barbara County APCD
Rule 333: Control of Emissions from Reciprocating Internal Combustion Engines
(Adopted 12/3/91, Amended 12/10/91, 4/17/97)

Applicability

≥50 bhp

Requirements and Standards*

Noncyclic Rich-Burn Engines**
NOx 50 ppmv or 90% control
ROC 250 ppmv
CO 4500 ppmv

Noncyclic Lean-Burn Engines**
NOx 125 ppmv or 80% control
ROC 750 ppmv
CO 4500 ppmv

Cyclically Operated Engines**
Oxygen in exhaust 6.5% or greater, and:
NOx 50 ppmv or 90% control
ROC 250 ppmv
CO 4500 ppmv

Diesel
NOx 8.4 g/Bhp-hr or 797 ppmv

* All ppmv limits are referenced to 15% oxygen, dry
** Noncyclic engines are engines which are not operated in a cyclic fashion. A cyclic engine varies in load by 40 percent or more of its rated power during recurring periods of 30 seconds or less, or is used dto power an oil well reciprocating pump.

Exemptions

Engines operating on fuel consisting of 75 percent or more of landfill gas
Engines exempt from permit
Engines operating fewer than 200 hours per year

Santa Barbara County APCD
Rule 333: Control of Emissions from Reciprocating Internal Combustion Engines (continued)

Administrative Requirements

Compliance Schedule
Noncyclically Operated Engines

Inspection & Maintenance Plan	3/2/92
Compliance Plan	3/2/92
Final Compliance	
33% of total Bhp	9/3/92
66% of total Bhp	6/3/93
100% of total Bhp	3/3/94

Cyclically Operated Engines

6.5% oxygen in exhaust	3/2/92
Compliance Plan	3/3/93
Final Compliance	3/3/94

Cyclics can be reclassified as noncyclics, but must then follow the noncyclic limits and schedule

Recordkeeping and Monitoring

Quarterly inspections with portable NOx monitor and inspection of engine operating parameters
Biennial source tests
Annual source tests for two consecutive years if engine is non-compliant
Engine operating log

Test Methods

NOx, CO, Oxygen	ARB Method 100
ROC	EPA Method 18 or 25
Fuel Composition	ASTM D-1945-81, ASTM D-3588-81, ASTM D-1072-80
Pollutant Emission Rate	EPA Method 19

Santa Barbara County APCD
Rule 333: Control of Emissions from Reciprocating Internal Combustion Engines (continued)

Alternative Control Plan

Control all engines 20 Bhp and larger
Achieve additional 20% tonnage of NOx emission reductions over Rule 333 control requirements
Continuous monitoring

Ventura County APCD
Rule 74.9: Stationary Internal Combustion Engines
(Adopted 7/21/81, Amended 7/2/85, 9/5/89, 12/3/91, 12/21/93)

Applicability

Gas-fired, LPG, or diesel fueled stationary internal combustion engine $\geq$ 50 hp, if such engines are not used in oil field drilling operations

Requirements and Standards*

CO 4500 ppmv

Ammonia 20 ppmv

Rich-Burn
NOx 25 ppmv or 96 percent control
ROC 250 ppmv

Lean-Burn
NOx 45 ppmv or 94 percent control
ROC 750 ppmv

Diesel
NOx 80 ppmv or 90 percent control
ROC 750 ppmv

Rich-Burn, waste gas
NOx 50 ppmv or 96 percent control
ROC 250 ppmv

Lean-Burn, waste gas
NOx 125 ppmv or 94 percent control
ROC 750 ppmv

Ventura County APCD
Rule 74.9: Stationary Internal Combustion Engines
(continued)

Requirements and Standards *(continued)

* All ppmv limits except ammonia measured at 15 percent oxygen and dry conditions; all ppmv limits except ammonia may be adjusted to higher ppmv levels for engines with efficiencies greater than 30 percent.

Exemptions

Engines rated less than 50 bhp
Engines operated less than 200 hours per year
Emergency standby engines operated only during emergencies and for no more than 50 hours per year for maintenance purposes
Engines used in research or teaching
Agricultural operations
Engine test stands used for evaluating engine performance
<100 bhp, emitting NOx ≤5 g/bhp-hr, used in cogeneration
Diesel engines limited to 15 percent or less annual capacity factor
Diesel engines used to power cranes and welding equipment

Administrative Requirements

Final compliance: 1/1/97 (1/1/02 if rule's previous requirements met by 9/5/89)
Engine Operator Inspection Plan required by 1/1/94
Recordkeeping: Inspection log
Annual usage
Annual source test

Test Methods

NOx, CO, Oxygen	ARB Method 100
ROC	EPA Method 25 or 18, referenced to methane
Heating value of fuel oil	ASTM D240-87
Heating value of gaseous fuels	ASTM D1826-77
Ammonia	BAAQMD Method ST-1B

Ventura County APCD
Rule 74.9: Stationary Internal Combustion Engines
(continued)

Test Methods (continued)

If a source test shows a violation, a source test or portable analyzer screening analysis is required for the next three scheduled inspections.

Bay Area Air Quality Management District
Regulation 9, Rule 8: Nitrogen Oxides and Carbon Monoxide from Stationary Internal Combustion Engines
(Adopted 1/20/93)

Applicability

$\geq$ 250 bhp; partly or completely gaseous fueled

Requirements and Standards

CO - 2000 ppmv @ 15% O_2

NOx -
Natural gas fuels
Rich-burn - 56 ppmv @ 15% O_2
Lean-burn - 140 ppmv @ 15% O_2
Waste derived fuels
Rich-burn - 210 ppmv @ 15% O_2
Lean-burn - 140 ppmv @ 15% O_2

Exemptions

Engines used solely as emergency standby sources of power
Engines < 250 bhp
Engines fired exclusively on liquid fuels
Engines used in agricultural operations
Engines $\leq$ 1000 bhp and < 200 hrs/year operation
Engines > 1000 bhp and < 100 hrs/year operation

Bay Area Air Quality Management District
Regulation 9, Rule 8: Nitrogen Oxides and Carbon Monoxide from Stationary Internal Combustion Engines
(continued)

Administrative Requirements

Authority to Construct submitted by 1/1/96
Be in compliance with all requirements by 1/1/97

Monitoring and Records

Initial source test required by 3/31/97; results submitted by 5/31/97
Maintain records of hours of operation for engines exempted due to low usage

Source Test Methods

NOx - ST-13 A or B
CO - ST-6
O_2 - ST-14

El Dorado County APCD
Rule 233: Stationary Internal Combustion Engines
(Adopted 10/18/94)

Applicability

> 50 bhp, operated on gaseous fuels, LPG, or diesel

Exemptions

Agricultural operations
$\leq$ 50 bhp engines
Engines operating < 200 hours per year
Emergency standby engines (maintenance limited to 50 hours/year)
Research and teaching
Test stands used for evaluating engine performance

El Dorado County APCD
Rule 233: Stationary Internal Combustion Engines
(continued)

Exemptions (continued)

Diesel engines with permitted capacity $\leq$ 15 %
Diesel engines used to power cranes and welding equipment

Standards

CO - 2000 ppmv
NOx -
Rich-burn - 90 ppmv @ 15% O_2
Lean-burn - 150 ppmv @ 15% O_2
Diesel - 600 ppmv @ 15% O_2

Engine Operation Inspection Plan required by 4/18/95

Compliance Schedule

Complete Authority to Construct by 5/15/95
Commence construction by 1/1/97
Demonstrate full compliance by 5/15/97 (5/15/99 if engine removed)

Monitoring and Records

Maintain inspection log
Documentation supporting exemption
Annual Emissions report

Test Methods

NOx - EPA Method 7E
CO - EPA Method 10
O_2 - EPA Method 3A

DRAFT

Kern County APCD
Rule 427: Stationary Piston Engines (Oxides of Nitrogen)
(Adopted 6/1/87, Amended 10/13/94, 1/25/96)

Applicability

> 50 bhp; all fuel types

Exemptions

Agricultural operations
Emergency standby engines operated < 200 hours/year
Engines used for firefighting or flood control
Laboratory engines used in research and testing
Engines operated exclusively for performance verification and testing
Portable engines not operated at the same site for more than one year

Requirements

For engines > 50 bhp: follow required maintenance schedule

For engines ≥ 250 bhp after 6/1/97:
CO - 2000 ppm
NOx - 50 ppm or 90% reduction (rich-burn)
- 125 ppm or 80 % reduction (lean-burn)
- 2 gm/bhp-hr if combustion modification used exclusively (125 ppm if no means to measure shaft power output) (lean burn)
- 600 ppm or 30% reduction (diesel)

- If engine efficiency exceeds 30 percent, ppm limits adjusted higher

Monitoring

For rich-burn engines, use automatic controls, equipment, procedures, or sensing devices that indicate NOx and CO concentrations. For rich-burn engines equipped with catalysts, use controls that will maintain air to fuel ratio within recommended limits.

Kern County APCD
Rule 427: Stationary Piston Engines (Oxides of Nitrogen)
(continued)

Monitoring

For lean-burn and diesel engines, monitor NOx and CO concentrations, or if catalysts are used, monitor flow rate of reducing compounds.

Administrative Requirements

Emission Control Plan required
Engine service log
Engine operating log for engines subject to emission limits
Source test required every calendar year

Test Methods

NOx - EPA Method 7E or ARB Method 100
CO - EPA Method 10 or ARB Method 100
O_2 - EPA Method 3 or 3A, or ARB Method 100

Compliance Schedule

For service requirements, submit emission control plan by 1/1/95; be in compliance by 5/31/95

For emissions limits, submit emissions compliance plan by 6/1/96; be in compliance by 6/1/97 (6/1/98 for cyclically loaded engines, 5/31/99 for public water districts)

DRAFT

San Diego County APCD
Rule 69.4: Stationary Reciprocating Internal Combustion Engines
(Adopted 9/27/94)

Applicability

$\geq$ 50 bhp, located at major stationary source

Exemptions

Used in connection with a structure for not more than four families
Agricultural operations
Engines operated for < 200 hours per year
Emergency standby engines operated $\leq$ 52 hours per year for maintenance
Emergency standby engines at nuclear generating stations operated $\leq$ 500 hours per year for maintenance
Military tactical deployable equipment operated $\leq$ 1,000 hours per year

Standards

CO - 4500 ppm
NOx - 50 ppm or 90% reduction (rich-burn, all fuels except waste derived)
NOx - 125 ppm or 80% reduction (lean-burn; also rich-burn, waste derived fuels)
- 700 ppm or 25% reduction (diesel)

Monitoring and Recordkeeping

Maintain maintenance records
Keep operating log for engines exempt due to low usage
Maintain monthly records for engine and control equipment parameters

Test Methods

ARB Method 100

Compliance Schedule

Submit permit application by 1/27/95 if modifications needed
Be in compliance by 5/31/95

DRAFT

Mojave Desert AQMD
Rule 1160: Internal Combustion Engines
(Adopted 12/20/93, Amended 10/26/94)

Applicability

$\geq$ 500 bhp, located in Federal Ozone Nonattainment Area

Requirements*

CO - 4500 ppmv
NOx - 50 ppmv or 90% reduction (rich-burn)
- 140 ppmv or 80% reduction (lean-burn)
- 700 ppmv or 30% reduction (diesel)
VOC - 106 ppmv, except 255 ppmv at SCG Newberry Spring facility

* All ppmv limits are to be corrected to dry conditions at 15% O_2

. Higher ppm limits allowed for engine efficiencies greater than 30 percent
Emission Control Plan required if facility proposes to aggregate emissions or requests an extension to the compliance schedule

Exemptions

< 500 bhp
Engines operating < 100 hours over four continuous calendar quarters
Emergency engines
Engines located outside of the Federal Ozone Nonattainment Area

Monitoring and Recordkeeping

Engine inspection required once every calendar quarter or after every 2,000 hours of operation, whichever is more frequent
Source test required every 12 months
Maintain log on each engine recording fuel use, maintenance performed, and other information required in Emission Control Plan

ARB/SSD December 3, 1997

Mojave Desert AQMD
Rule 1160: Internal Combustion Engines
(continued)

Test Methods

NOx - EPA Method 7E
CO - EPA Method 10
VOC - EPA Methods 18, 25, and/or 25A
O_2 - EPA Method 3A
Exempt compounds - ASTM Method D 4457-85

Compliance Schedule

Final Compliance for SCG by 11/3/95 to 1/17/97 (engine-specific)

Final Compliance for PG&E:
30% of installed horsepower by 11/30/96
60% of installed horsepower by 6/30/97
100% of installed horsepower by 6/30/98

Yolo-Solano AQMD
Rule 2.32: Stationary Internal Combustion Engines
(Adopted 8/10/94)

Applicability

> 50 bhp; operated on gaseous fuels, LPG, or diesel

Exemptions

Engines used for agricultural operations
Engines $\leq$ 50 bhp
Engines operated < 200 hours/year
Emergency standby engines operated $\leq$50 hours/year for maintenance purposes
Engines used in research or teaching programs
Engines used in test stands to evaluate engine performance
Diesel engines with a permitted capacity factor $\leq$ 15%

Yolo-Solano AQMD
Rule 2.32: Stationary Internal Combustion Engines
(continued)

Exemptions (continued)

Diesel engines used to power cranes and welding equipment

Limits

CO - 2,000 ppmv

5/31/95 limits:
NOx - 9.5 gm/bhp-hr or 640 ppmv (rich-burn)
- 10.1 gm/bhp-hr or 740 ppmv (lean-burn)
- 9.6 gm/bhp-hr or 700 ppmv (diesel)

If 5/31/95 limits not met, then following limits apply by 5/31/97:
NOx - 90 ppmv (rich-burn)
- 150 ppmv (lean-burn)
- 600 ppmv (diesel)

If 5/31/95 and 5/31/97 limits not met, engine must be removed by 5/15/99.

Engine operator inspection plan required

Inspection log required

Test Methods

NOx - EPA Method 7E
CO - EPA Method 10
O_2 - EPA Method 3A
Heating value of oil - ASTM Method D240-87
Heating value of gaseous fuel - ASTM Method D1826-77

Sacramento Metropolitan AQMD
Rule 412: Stationary Internal Combustion Engines Located at Major Stationary Sources of NOx
(Adopted 6/1/95)

Applicability

All engines > 50 bhp at major stationary sources

Exemptions

Emergency standby
Agricultural operations
Test stands
Emission control evaluation
Nonroad engines
Motor vehicles
Flight line engines

Limits

After 7/1/95:

	NOx	CO	NMHC
Rich-burn	50	4000	250
Lean-burn	125	4000	750
Diesel	700	4000	750

NOx limits after 5/31/97:
Rich-burn - 25 ppmv or 90% reduction
Lean-burn - 65 ppmv or 90% reduction
Diesel - 80 ppmv or 90% reduction

Rich-burn engines exempt from 5/31/97 NOx limits if operated fewer than 40 to 200 hours per year, depending on size. Diesel engines exempt from 5/31/97 NOx limits if engines operate fewer than 200 to 1435 hours per year, depending on size. If retrofit is required to meet the 5/31/97 limits, the 7/1/95 limits do not apply.

Compliance date extended to 5/31/99 if engine removed from service.

Sacramento Metropolitan AQMD
Rule 412: Stationary Internal Combustion Engines
Located at Major Stationary Sources of NOx
(continued)

Test Requirements

Source test required every 8,760 hours of operation or every 5 years, whichever is shorter.

Monitoring and Recordkeeping

Operational record required

Test Methods

NMHC - EPA Method 25, or 25A and 18

For spark-ignited engines:
NOx, CO, O_2 - ARB Method 100

For diesel engines:
NOx - EPA Method 7E
CO - EPA Method 10
O_2 - EPA Method 3A

San Joaquin Valley Unified APCD
Rule 4701: Stationary Internal Combustion Engines
(Adopted 5/21/92, Amended 12/17/92, 10/20/94, 3/16/95, 12/19/96)

Applicability

Engines rated greater than 50 brake horsepower and requiring a permit

Exemptions

Agricultural operations
Standby engines
Engines used exclusively for fire fighting or flood control

San Joaquin Valley Unified APCD
Rule 4701: Stationary Internal Combustion Engines
(continued)

Exemptions (continued)

Laboratory engines used in research and testing
Engines used for performance verification and testing
Gas turbines
Portable engines
Natural gas-fired engines, when using other fuels during a natural gas curtailment, if operated no more than 336 hours per year on the other fuel
Military Tactical Equipment
Transportable engines
Engines rated at 50 brake horsepower or fewer

Limits

Table 1

Category	NOx	CO
Rich-burn	9.5 gm/bhp-hr or 640 ppmv	2000 ppmv
Lean-burn	10.1 gm/bhp-hr or 740 ppmv	2000 ppmv
Diesel	9.6 gm/bhp-hr or 700 ppmv	2000 ppmv

Table 2

Category	NOx	CO
Rich-burn	90 ppmv or 80% reduction	2000 ppmv
Lean-burn	150 ppmv or 70% reduction	2000 ppmv
Diesel	600 ppmv or 20% reduction	2000 ppmv

San Joaquin Valley Unified APCD
Rule 4701: Stationary Internal Combustion Engines
(continued)

Table 3

Category	NOx	CO	VOC
Waste derived gaseous fuel	125 ppmv or 80% reduction	2000 ppmv	750 ppmv
Rich-burn oil well pumps	300 ppmv	2000 ppmv	(none)
Other rich-burn engines	50 ppmv or 90% reduction	2000 ppmv	250 ppmv
Lean-burn	75 ppmv or 85% reduction	2000 ppmv	750 ppmv
Diesel or dual fuel	80 ppmv or 90% reduction	2000 ppmv	750 ppmv

Table 3 limits not applicable to engines operating fewer than 1,000 hours per year.

Compliance Schedule

Emission Control Plan submitted by 12/19/97
If engine to be modified, permit application required by 12/19/97 or 24 months before compliance required, whichever is later

-Non-cyclic natural gas-fired engines in Central and Western Kern County Fields:

Category	Table 1	Table 2	Table 3
Central	NR*	12/31/95	5/31/99
Western	NR	12/31/95	5/31/01

* NR = not required

San Joaquin Valley Unified APCD
Rule 4701: Stationary Internal Combustion Engines
(continued)

-Non-natural gas fueled engines, operating on those fuels on 10/20/94, in Central and Western Kern County Fields, major NOx sources:
-Cyclic loaded natural gas-fired engines in Central and Western Kern County Fields:
-Other engines at major NOx sources operating outside of the area west of Interstate Highway 5 in Fresno, Kern, and Kings counties:

Category	Table 1	Table 2	Table 3
Public Water Districts	NR*	5/31/99	NR
Rich-burn oil well pumps			
-Early RACT Compliance	5/31/95	NR	12/31/97
Delayed RACT Compliance	NR	5/31/97	NR
Other Western Kern Co. Field engines			
-Early RACT Compliance	5/31/95	NR	5/31/01
-Delayed RACT Compliance	NR	5/31/97	5/31/01
All other engines			
-Early RACT Compliance	5/31/95	NR	5/31/99
-Delayed RACT Compliance	NR	5/31/97	5/31/99

-All Other Engines:

Category	Table 1	Table 2	Table 3
Rich-burn oil well pumps			
-Early Compliance	NR	NR	12/31/97 -
Delayed non-Westside Comp.	NR	5/31/99	NR
-Delayed Westside Comp.	NR	5/31/01	NR
All other engines			
-Non-Westside Compliance	NR	NR	5/31/99
-Westside Compliance	NR	NR	5/31/01

* NR = not required

Operators allowed to use an alternative emissions compliance plan in place of limits for individual engines.

San Joaquin Valley Unified APCD
Rule 4701: Stationary Internal Combustion Engines
(continued)

Monitoring Equipment

For engines with external control devices, CEMS for NOX, CO, and O2, or alternate monitoring system
For engines without external control devices, monitor operational characteristics as recommended by engine manufacturer or emission control supplier

Administrative Requirements

Emissions Control Plan required
Maintain engine operating log

Testing

Initial source test required; every 24 months thereafter

Annual testing of a representative sample of engines allowed for sites with multiple identical engines

Test Methods

NOx - EPA Method 7E, or ARB Method 100
CO - EPA Method 10, or ARB Method 100
O_2 - EPA Method 3 or 3A, or ARB Method 100
VOC - EPA Method 25 or 18, referenced as methane
BHP - Any method approved by the APCO and federal EPA

San Luis Obispo County APCD
Rule 431, Stationary Internal Combustion Engines
(adopted 11/13/96)

Applicability

Engines rated greater than 50 brake horsepower

Exemptions

Engines rated at 50 brake horsepower or fewer
Engines operated fewer than 200 hours per year
Emergency standby engines only operated during emergencies and maintenance operations; maintenance limited to 100 hours per year
Engines used in research or teaching programs
Engines used in agricultural operations
Engine test stands used for evaluating engine performance
Diesel engines used to power cranes and welding equipment

Emission Requirements

Ammonia: no more than 20 ppmv

Engine Type	NOX	CO (ppmv)
Rich-burn	50 ppmv or 90% reduction	4500
Lean-burn	125 ppmv or 80% reduction	4500
Diesel	600 ppmv or 30% reduction	4500

Source Testing Requirements

Every 8760 hours of engine operation or every three years, whichever comes first

Administrative Requirements

Inspection plan required
Inspections required every quarter or after 2,000 hours of operation, but no less frequent than once a year
Inspection log required
Annual reporting of fuel usage and maintenance

San Luis Obispo County APCD
Rule 431, Stationary Internal Combustion Engines
(continued)

Compliance Schedule

November 13, 1996, for engines applying for an initial permit or new facilities.

For spark-ignited engines required to modify, complete Authority to Construct application must be submitted by May 1, 1999; final compliance by May 1, 2000.

For diesel engines, after May 1, 2000, upon retrofit or replacement of the engine.

APPENDIX D

EMISSIONS DATA

Following are tables summarizing emissions data for IC engines. Table D-1 summarizes data from the ARB BACT Clearinghouse for IC engines. This Clearinghouse maintains a list of best available control technology (BACT) determinations. These determinations are made for new or modified stationary sources with emissions increases above certain specified levels. Also included in this list are permit limits in cases where BACT was not required. Although these data are for new engines, in many cases existing engines can be retrofitted with the same technology with similarNOXx reduction results.

Table D-2 summarizes source test data for IC engines from the Ventura County Air Pollution Control District. All engines were gas-fired. Following is an explanation of the meaning for each column in Table D-2:

MANUFACTURER - engine manufacturer
MODEL - engine model designated by the manufacturer
HORSEPOWER - maximum continuous brake horsepower rating of engine
R/L - an"r" signifies a rich-burn engine; an "l" signifies a lean-burn engine.
CONTROLS - description of controls on engine; "baseline" indicates the source test was a baseline test on an uncontrolled engine.
ST - status of engine; d = deleted, c = operational, m = electrified.
NOX IN - NOx emissions in parts per million by volume (ppmv) dry, corrected to 15% oxygen, before the exhaust control device. In some cases, for prestratified (PSC) engines, the "NOX IN" lists NOx emissions in ppmv with the PSC system turned off. If exhaust controls are not used, or emissions were only measured after the control device, this value is listed as "0".
NOX OUT - NOx emissions in ppmv dry, corrected to 15% oxygen, in the exhaust for engines not using exhaust controls, after the control device for engines using exhaust controls.
NOX REDUCED - the percentage reduction in NOx
CO OUT - carbon monoxide emissions in ppmv dry, in the exhaust for engines not using exhaust controls, after the control device for engines using exhaust controls.
NMHC PPM - nonmethane hydrocarbons in parts per million of carbon, dry, in the exhaust for engines not using exhaust controls, after the control device for engines using exhaust controls.
DATE TEST - date of the source test, month/day/year
O2% - oxygen concentration of the exhaust in percent
NMHC 15% O2 - nonmethane hydrocarbons in parts per million of carbon, dry, corrected to 15% oxygen, in the exhaust (after the control device for engines using exhaust controls).

CO 15% O2 - carbon monoxide emissions in ppmv dry, corrected to 15% oxygen, in the exhaust for engines not using exhaust controls, after the control device for engines using exhaust controls.
QST - exhaust flow rate in cubic feet per minute at standard conditions.
****** - value exceeds space allotted.

Table D-3 summarizes source test data from Santa Barbara County, while Table D-4 summarizes source test data from San Diego County.

TABLE D-1
ARB BACT Clearinghouse Data on IC Engine Controls

BACT Det. Date	Engine	Fuel Type	Horsepower	Duty Cycle	NOx gm/hp-hr	Control Methods	% Efficiency	District
Jan. 8, 1981	Cooper	NG	4130	Continuous	1.75	Clean Burn	Unknown	BAAQMD
March 27, 1981	Waukesha	NG	526	Operates 2/3 of year	1.65	NSCR	90	BAAQMD
Dec. 2, 1982	Cooper Ajax DPC 180	NG	180	Cont., 80% of full power	1.8	Clean Burn	Unknown	Ventura
May 12, 1983	Unknown	NG	930	Continuous	0.9	Catalyst	Unknown	San Diego
Sept. 30, 1983	Waukesha	NG	200	Continuous	0.7	NSCR	96.7	Ventura
Oct. 19, 1983	Waukesha	NG	2133	Cont., 41% of full power	1.5	NSCR	86	Kern
Oct. 19, 1983	Waukesha	NG	1280	Cont., 32% of full power	1.5	NSCR	86	Kern
March 5, 1984	Waukesha L 7042	NG	2133	Continuous	1	Catalyst	Unknown	MBUAPCD
May 29, 1984	Waukesha	NG	1689	Cont., 64% of full power	1.09	NSCR	90	Kern
July 23, 1984	Transamerica DeLaval	Dual Fuel	3656	Continuous	3.7	Stratified Charge	Unknown	MBUAPCD
Sept. 16, 1984	Cooper-Superior	LG	2000	Continuous	1.5	Clean Burn	Unknown	MBUAPCD
Nov. 14, 1984	Superior 16SGTA	LG	2650	Cont., 94% of full power	1.5	Clean Burn	60	Kern
Nov. 14, 1984	Clark HRA-6	NG	600	Continuous	3.1	SCR	70	SCAQMD
Jan. 28, 1985	Fairbanks-Morse	LG	2000	Continuous	1.5	Clean Burn	Unknown	MBUAPCD
March 1985	Cooper-Superior 16SGTA	LG	2650	Continuous	1.5	Clean Burn	86	BAAQMD
Aug. 29, 1985	Cooper-Superior	LG	1100	Continuous	1.5	Clean Burn	Unknown	BAAQMD
Dec. 2, 1985	Caterpillar G342	NG	225	Continuous	0.8	NSCR	90	Ventura
Dec. 2, 1985	Cooper-Superior	LG	2650	Continuous	1.5	Clean Burn	Unknown	BAAQMD
May 1986	DeLaval	DG	7000	Continuous	2	Clean Burn	Unknown	BAAQMD
July 7, 1986	Cummins KTTA-50CC	Diesel	1365	Continuous	5.4	WI, IR	39	San Diego
August 7, 1986	Caterpillar G3306-TA	NG	195	Continuous	1.5	NSCR	90	Ventura
Sept. 16, 1986	Waukesha	DG	865	Continuous	2	Prestratified Charge	Unknown	Sacramento
Nov. 13, 1986	Cooper	LG	2650	Continuous	0.5	Clean Burn	70	SCAQMD
Nov. 13, 1986	Cooper	LG	825	Continuous	0.8	Clean Burn	70	SCAQMD
Dec. 31, 1986	Waukesha F 3521 GL	DG and NG	773	Continuous	2	Clean Burn	Unknown	Ventura
March 9, 1987	Caterpillar 3516TA	NG	1150	Hours per day: 22	1.4	Clean Burn	92	San Diego
Nov. 19, 1987	Unknown	Diesel	Unknown	Unknown	Unknown	TC, SCAC, 4 deg IR	Unknown	Santa Barbara
Dec. 18, 1987	Alco 12V-251-SI	NG	2000	Continuous	0.75	Clean Burn	Unknown	Kings
Nov. 25, 1988	Caterpillar G398	NG	525	Continuous	1	NSCR	Unknown	Kern
Aug. 30, 1989	Det. Diesel 16V-149TIB	Diesel	2340	Emergency Standby	1.5	TC, IC, SCR	85	SCAQMD
Aug. 31, 1989	Caterpillar 3606	Diesel	2100	One-fourth of full power	2.4	SCR	80	SCAQMD
Oct. 27, 1989	Caterpillar D398TA	Diesel	850	Continuous for 90 days	7.1	IR of 5 deg	Unknown	MBUAPCD
Dec. 8, 1989	Caterpillar	Diesel	235	Emergency firewater pump	14	None	0	Kern
Jan. 12, 1990	Unknown	Diesel	Unknown	Temporary	Unknown	SCR	Unknown	MBUAPCD
Jan. 12, 1990	Unknown	NA	Unknown	Temporary	Unknown	partial elect.	Unknown	MBUAPCD
Feb. 7, 1990	GM EMD 12-567	Diesel	1120	Continuous	0.4	SCR	94	SCAQMD
Feb. 7, 1990	Cooper Bessemer JS-8-1	Diesel	1420	Continuous	0.4	SCR	94	SCAQMD
Feb. 7, 1990	Cooper Bessemer LSV-16	Diesel	2500	Continuous	0.4	SCR	94	SCAQMD
July 17, 1990	Caterpillar G398TA	NG	700	Continuous	0.79	NSCR	92	Santa Barbara
Dec. 21, 1990	Cummins KTA-1150	Diesel	480	Temporary, 360 hrs max.	11.2	IR of 6 deg	Unknown	MBUAPCD
Dec. 21, 1990	Cummins 6BT 3.9	Diesel	140	Temporary, 360 hrs max.	11.2	IR of 6 deg	Unknown	MBUAPCD

TABLE D-1 (Continued)

BACT Det. Date	Engine	Fuel Type	Horsepower	Duty Cycle	NOx gm/hp-hr	Control Methods	% Efficiency	District
Dec. 21, 1990	Cummins 4BT 3.9	Diesel	70	Temporary, 360 hrs max.	11.2	IR of 6 deg	Unknown	MBUAPCD
Dec. 21, 1990	Detroit Diesel 8V92TA	Diesel	400	Temporary, 360 hrs max.	11.2	IR of 6 deg	Unknown	MBUAPCD
June 1, 1991	Caterpillar 3512	NG, LPG	525	Hours per day: 20	1.5	NSCR	96	SCAQMD
Oct. 24, 1991	Waukesha	NG, LPG	200	Continuous	1.5	NSCR	86	SJVUAPCD
Nov. 12, 1991	GM 500 cu. in.	NG	380	One-third of full power	1.1	NSCR	90	SJVUAPCD
Nov. 12, 1991	Waukesha	Propane, NG	200	Unknown	1.5	NSCR	Unknown	SJVUAPCD
Nov. 15, 1991	Cummins-Onan 45 EM	LPG	82	Emergency Standby	1.5	NSCR	60	SJVUAPCD
Dec. 2, 1991	Waukesha	NG, Propane	200	Continuous	1.5	NSCR	86	SJVUAPCD
Jan. 6, 1992	Unknown	Diesel	211	Continuous	6.2	TC, WI, IR	64	SJVUAPCD
Feb. 25, 1992	Cooper-Superior 16SGTA	LG	2650	Continuous	0.8	Clean Burn	Unknown	San Diego
March 26, 1993	Waukesha 5900GL	DG, NG	913	Continuous	1.25	Clean Burn	Unknown	BAAQMD
June 18, 1993	Unknown	Diesel	951	Unknown	6.6	TC, IC, 4 deg IR	40	SJVUAPCD
June 15, 1994	Caterpillar 3412	Diesel	800	Unknown	Unknown	4 deg IR	Unknown	Feather River
May 2, 1995	Ford LSG-875	TV, LPG	175	Unknown	50 ppm	NSCR	90	SJVUAPCD
May 18, 1995	Caterpillar 3306TA	NG	130	Unknown	0.15	NSCR	Unknown	Ventura
July 20, 1995	Generac 94A01244-S	Propane	72	Emergency Standby	Unknown	NSCR	80	SJVUAPCD

LIST OF ABBREVIATIONS:

BACT Det. Date = Best Available Control Technology Determination Date
Cost-Effect = Cost-effectiveness in dollars per pound of NOx removed
deg = Degrees of crankshaft rotation
DG = Digester gas
IC = Intercooled
IR = Injection Timing Retard
LG = Landfill gas
NA = Not applicable
NG = Natrual gas
NSCR = Nonselective catalytic reduction
SCAC = Separate circuit aftercooler
SCR = Secective catalytic reduction
TC = Turbocharged
WI = Water injection

DISTRICT ABBREVIATIONS:

BAAQMD = Bay Area Air Quality Management District
Feather River = Feather River Air Quality Management District
Kern = Kern County Air Pollution Control District
Kings = Kings County Air Pollution Control District
MBUAPCD = Monterey Bay Unified Air Pollution Control District
SCAQMD = South Coast Air Quality Management District
SJVUAPCD = San Joaquin Valley Unified Air Pollution Control District
Sacramento = Sacramento Metropolitan Air Quality Management District
San Diego = San Diego County Air Pollution Control District
Santa Barbara = Santa Barbara County Air Pollution Control District
Ventura = Ventura County Air Pollution Control District

Table D-2

VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Ingersoll-Rand	JVG-8	225	r	HoustonInd Cat	c	564	32	94.300	8613	84.000	12/10/87	0.200	23.942	2454.913	0
Ingersoll-Rand	JVG-6	165	r	HoustonInd Cat	c	457	29	93.700	7358	100.000	03/04/88	0.100	28.365	2087.125	0
Caterpillar	G379	295	r	Houston Ind CC	d	786	31	96.100	3686	184.000	12/10/87	0.400	52.956	1060.849	0
Tecogen	CM-60	87	r	Englehard Cat	c	7452	10	98.700	5143	6.000	06/18/90	0.100	2.000	1452.000	117
Tecogen Cogen	CM-60	87	r	Englehard Cat	c	0	9	0.000	551	0.000	06/18/92	1.100	0.000	164.000	7484
Tecogen	CM-60	87	r	Englehard Cat	c	732	1	99.800	2653	11.000	06/18/90	0.100	3.000	777.000	115
Tecogen Cogen	CM-60	87	r	Englehard Cat	c	0	1	0.000	1271	0.000	06/18/92	1.000	0.000	377.000	6361
Tecogen Cogen	CM-75	108	r	Englehard Cat	c	0	39	0.000	1583	0.000	06/18/92	1.500	0.000	481.000	8364
Waukesha	F3521GU	391	r	R-B NSCR	c	174	4	97.900	*****	106.000	12/11/89	0.010	30.000	11040.000	585
Waukesha	F3521GU	391	r	R-B NSCR	c	495	22	95.500	*****	82.000	06/11/90	0.100	23.000	3401.000	528
Caterpillar	G3306	67	r	R-B NSCR	c	393	23	94.100	*****	76.000	12/11/89	0.100	22.000	5229.000	193
Waukesha	140GZ	116	r	PSC		840	24	97.100	154	137.000	12/21/86	9.100	68.500	77.000	0
Waukesha	P9390G	800	r	PSC PreStrat Ch	c	44	44	0.000	275	44.000	10/20/87	6.700	18.282	114.261	0
Waukesha	P9390G	800	r	PSC heat/cogen	c	0	43	0.000	190	173.700	06/27/89	7.450	0.000	83.200	1042
Waukesha	P9390G	800	r	PSC heat/cogen	c	0	23	0.000	344	27.000	07/30/92	6.740	11.390	143.000	723
Waukesha	P9390G	800	r	PSC heat/cogen	c	0	19	0.000	209	41.000	06/27/89	7.120	0.000	89.300	1145
Waukesha	P9390G	800	r	PSC heat/cogen	c	0	33	0.000	336	35.000	07/30/92	7.190	14.920	144.520	746
Waukesha	P9390G	796	r	PSC PreStrat Ch	c	845	50	94.100	334	40.000	03/24/87	6.900	16.857	140.757	0
Waukesha	P9390G	796	r	DGEC-PSC AirEGR	c	39	39	0.000	323	43.000	12/29/87	9.000	21.319	160.143	0
Waukesha	P9390G	800	r	PSC heat/cogen	c	0	22	0.000	202	30.000	06/27/89	6.770	0.000	84.300	992
Waukesha	P9390G	800	r	PSC Heat/Cogen	c	0	20	0.000	267	0.000	05/15/90	7.500	0.000	118.000	2386
Waukesha	P9390G	800	r	PSC heat/cogen	c	0	29	0.000	335	24.000	07/30/92	6.070	9.420	133.220	690
Caterpillar	G379	330	r	PSC	c	0	24	0.000	292	85.300	06/27/89	8.170	0.000	135.000	516
Caterpillar	G379	330	r	PSC	c	954	63	93.400	388	27.500	12/12/91	2.120	12.840	181.000	575
Caterpillar	G379	330	r	PSC	c	0	37	0.000	415	430.000	07/29/92	8.480	204.000	197.000	292
Caterpillar	G379	330	r	Baseline	c	898	898	0.000	349	104.900	06/19/86	1.900	32.574	108.374	0
Caterpillar	G379	330	r	PSC PreStrat Ch	c	44	44	0.000	396	208.900	11/24/86	8.800	101.860	193.091	0
Caterpillar	G379	330	r	PSC PreStrat Ch	c	14	14	0.000	466	113.500	03/23/87	9.000	56.273	231.042	0
Caterpillar	G379	330	r	PSC	c	0	42	0.000	370	122.500	06/27/89	9.580	0.000	192.000	548
Caterpillar	G379	330	r	PSC	c	0	29	0.000	443	377.000	07/29/92	8.570	180.240	211.740	294
Caterpillar	G379	330	r	PSC PreStrat Ch	c	23	23	0.000	359	46.600	03/23/87	8.600	22.353	172.203	0
Caterpillar	G379	330	r	PSC PreStrat Ch	c	14	14	0.000	354	134.000	03/03/88	8.300	62.746	165.762	0
Caterpillar	G379	330	r	PSC	c	0	43	0.000	285	53.300	06/27/89	8.790	0.000	139.000	516
Caterpillar	G379	330	r	PSC	c	0	39	0.000	380	0.000	05/15/90	8.400	0.000	179.000	199
Caterpillar	G379	330	r	PSC	c	852	68	92.100	351	10.000	12/12/91	1.310	4.450	156.000	410
Caterpillar	G379	330	r	PSC	c	0	33	0.000	334	677.000	07/29/92	8.650	325.000	161.000	296

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VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Caterpillar	G398	500	r	None?	d	0	26	0.000	468	367.000	07/30/92	12.020	243.000	311.000	431
Caterpillar	G398	500	r	None?	d	0	26	0.000	473	98.000	07/30/92	8.590	47.000	227.000	311
Caterpillar	G353	250	r	JM CC	d	0	29	0.000	208	0.000	03/27/92	2.000	3.000	63.000	169
Clark	HRA-6	660	l	Sel Cat Convert	c	672	82	87.800	284	227.000	03/26/87	14.100	196.956	246.412	0
Clark	HRA-6	660	l	Nergas SCR	c	1159	155	86.600	290	200.900	08/26/88	13.500	160.177	231.216	0
Clark	HRA-6	660	l	Nergas SCR	c	619	72	88.400	267	112.500	05/23/89	13.900	95.000	225.000	2642
Clark	HRA-6	660	l	Nergas SCR	c	1237	222	82.100	256	0.000	04/23/90	13.000	0.000	191.000	2246
Clark	HRA-6	660	l	Nergas SCR	c	679	83	87.776	402	387.000	06/12/92	15.200	401.000	416.000	719
Clark	HRA-6	660	l	KleenaireProces	c	1094	180	83.500	246	346.800	12/22/86	14.200	305.391	216.627	0
Clark	HRA-6	660	l	Nergas SCR	c	885	104	88.200	301	163.700	05/06/88	13.600	132.305	243.274	0
Clark	HRA-6	660	l	Nergas SCR	c	636	55	91.352	481	260.000	05/02/89	13.100	196.667	363.833	0
Clark	HRA-6	660	l	Nergas SCR	c	1312	166	87.300	239	0.000	04/23/90	13.100	0.000	180.000	2246
Clark	HRA-6	660	l	Nergas SCR	c	562	64	88.612	167	300.000	06/12/92	14.400	273.000	152.000	631
Tecogen	CM-200	291	l	Englehard Cat	c	354	10	97.200	*****	48.000	12/07/89	0.100	16.000	7574.000	358
Tecogen	CM-200	291	l	Englehard Cat	c	646	36	94.500	1433	13.000	04/13/90	0.100	4.000	405.000	370
Ingersoll-Rand	XVG	350	r	TWC	m	195	2	99.000	*****	109.000	01/07/88	1.500	33.149	6489.696	0
Ingersoll-Rand	XVG	350	r	TWC	m	81	48	40.700	*****	638.000	08/25/88	8.900	313.683	6286.450	0
Minneapolis-Mol	800-6A	160	r	HIS, DN S1475	c	561	5	99.000	*****	225.000	12/05/91	0.020	63.880	5969.230	89
Minneapolis-Mol	800-6A	160	r	HIS, DN/S1475	c	0	7	0.000	3877	76.000	03/11/92	0.100	21.000	1095.000	91
Cooper Bessemer	GMVA-8	1100	l	Clean Burn ECS	c	64	64	0.000	130	29.000	02/06/86	16.600	39.791	178.372	0
Cooper Bessemer	GMVA-8	1100	l	Clean Burn ECS	c	65	65	0.000	120	47.000	05/05/86	16.800	67.634	172.683	0
Cooper Bessemer	GMVA-8	1100	l	Clean Burn ESC	c	218	218	0.000	123	0.000	08/22/86	0.000	0.000	164.932	0
Cooper Bessemer	GMVA-8	1110	l	Clean Burn ESC	c	71	71	0.000	141	0.000	10/31/86	0.000	0.000	189.068	0
Cooper Bessemer	GMVA-8	1100	l	Clean Burn ECS	c	238	238	0.000	81	0.000	02/06/87	0.000	0.000	108.614	0
Cooper Bessemer	GMVA-8	1100	l	Clean Burn ESC	c	97	97	0.000	0	0.000	05/08/87	0.000	0.000	0.000	0
Cooper Bessemer	GMVA-8	1100	l	Clean Burn ESC	c	248	248	0.000	0	0.000	01/08/88	0.000	0.000	0.000	0
Cooper Bessemer	GMVA-8	1100	l	Clean Burn ESC	c	0	1096	0.000	0	0.000	10/30/89	15.400	0.000	0.000	5021
Cooper Bessemer	GMVA-8	1100	l	Clean Burn ESC	c	0	302	0.000	59	43.000	01/13/89	16.070	0.000	72.300	5499
Tecogen	CM-75	108	r	Englehard Cat	c	606	64	89.500	5095	21.000	03/30/89	0.100	0.000	0.000	156
Caterpillar	G398	412	r	ECS NSCR	c	0	37	0.000	820	0.000	05/11/90	0.010	0.000	231.000	0
Caterpillar	G398	412	r	ECS NSCR	c	0	24	0.000	3755	60.770	12/07/90	0.050	17.000	1063.000	0
Caterpillar	G398	412	r	ECS NSCR	c	591	26	95.700	7891	168.000	12/19/91	0.100	48.000	2227.000	305
Caterpillar	G398	412	r	ECS NSCR	c	0	18	0.000	2961	0.000	05/11/90	0.010	0.000	836.000	0
Caterpillar	G398	412	r	ESC NSCR	c	0	20	0.000	*****	315.000	10/19/90	0.060	89.000	3037.000	0
Caterpillar	G398	412	r	ECS NSCR	c	617	39	93.700	3484	111.000	12/19/91	0.100	32.000	986.000	224
Caterpillar	G398	412	r	Catalyst(noPSC)	c	0	8	0.000	2062	46.900	07/06/89	0.090	0.000	584.700	465

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VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Caterpillar	G398	412	r	ECS NSCR	c	0	25	0.000	4859	0.000	05/11/90	0.050	0.000	1375.000	0
Caterpillar	G398	412	r	PSC Turbo	c	0	74	0.000	3725	799.000	05/17/90	0.300	229.000	1067.000	410
Caterpillar	G398	412	r	PSC Turbo	c	0	21	0.000	1432	118.000	10/19/90	0.040	33.000	405.000	0
Caterpillar	G398	412	r	PSC Turbo	c	0	40	0.000	5500	53.000	12/19/91	0.200	15.000	1568.000	230
Ajax	DCP-115	140	l	None	d	0	89	0.000	198	********	05/17/90	14.700	********	188.000	422
Waukesha	GMVA-8	165	r	ECS NOx Control		384	23	94.000	9283	0.000	07/02/86	0.000	0.000	2752.246	0
Waukesha	GMVA-8	165	r	ECS NOx Control		174	19	89.100	*****	394.100	06/15/87	1.000	116.844	8894.472	0
Superior	16SGTA	2650	l		e	42	42	0.000	0	0.000	08/14/86	0.000	0.000	0.000	0
Superior	16SGTA	2650	l		e	52	52	0.000	307	0.000	08/25/87	0.000	0.000	152.210	0
Superior	16SGTA	2650	l		e	30	30	0.000	339	0.000	01/26/88	0.000	0.000	168.076	0
Superior	16SGTA	2650	l		e	24	24	0.000	323	0.000	04/26/88	0.000	0.000	160.143	0
Superior	16SGTA	2650	l		e	49	49	0.000	362	0.000	08/18/88	0.000	0.000	179.479	0
Superior	16SGTA	2650	l		e	35	35	0.000	287	50.000	09/06/88	11.600	31.720	182.075	0
Superior	16SGTA	2650	l		e	35	35	0.000	287	50.000	10/06/88	8.100	23.047	132.289	0
Superior	16SGTA	2650	l		e	45	45	0.000	374	0.000	12/20/88	8.440	0.000	177.095	0
Superior	16SGTA	2650	l	Clean Burn	e	0	79	0.000	0	0.000	06/16/89	7.400	3.600	119.100	0
Superior	16SGTA	2650	l	Clean Burn	e	0	44	0.000	237	19.800	06/01/90	7.980	0.000	0.000	6377
Superior	16SGTA	2650	l		e	43	43	0.000	0	0.000	08/14/86	0.000	0.000	0.000	0
Superior	16SGTA	2650	l		e	39	39	0.000	331	0.000	08/25/87	0.000	0.000	164.109	0
Superior	16SGTA	2650	l		e	76	76	0.000	356	0.000	01/26/88	0.000	0.000	176.504	0
Superior	16SGTA	2650	l		e	75	75	0.000	377	0.000	04/26/88	0.000	0.000	186.916	0
Superior	16SGTA	2650	l		e	89	89	0.000	434	0.000	08/18/88	0.000	0.000	215.176	0
Superior	16SGTA	2650	l		e	77	77	0.000	407	6.000	09/07/88	8.900	2.950	200.108	0
Superior	16SGTA	2650	l		e	77	77	0.000	407	6.000	10/07/88	10.800	3.505	237.752	0
Superior	16SGTA	2650	l		e	71	71	0.000	268	0.000	12/20/88	8.260	0.000	125.095	0
Superior	16SGTA	2650	l	Clean Burn	e	0	82	0.000	0	0.000	06/16/89	7.500	4.200	141.000	0
Superior	16SGTA	2650	l	Clean Burn	e	0	78	0.000	362	21.900	06/01/90	8.040	0.000	0.000	5055
Tecogen	CM-60	79	r	None	e	0	177	0.000	338	23.000	03/29/89	3.200	0.000	0.000	146
Waukesha	L7042G	775	r	Englehard NSCR	c	0	3	0.000	7061	653.000	06/19/92	0.100	185.000	2003.000	350
Waukesha	L7042G	775	r	Englehard NSCR	c	0	10	0.000	2802	********	06/19/92	0.100	308.000	795.000	353
Waukesha	L7042G	775	r	Englehard NSCR	c	0	32	0.000	*****	********	06/19/92	0.100	341.000	2922.000	336
Waukesha	L7042G	775	r	Englehard NSCR	c	0	19	0.000	6875	********	06/19/92	0.500	694.000	1988.000	228
White Superior	G-8258	625	r	Engelhard Deoxo		572	5	99.100	6000	258.000	12/17/82	0.010	72.867	1694.591	0
White Superior	G-8258	625	r	Engelhard Deoxo		0	0	0.000	210	165.000	12/17/82	0.200	47.029	59.855	0
White Superior	G-8258	625	r	Engelhard Deoxo		2	2	0.000	*****	270.000	12/17/82	0.010	76.257	3191.479	0
Waukesha	L7042G	858	r	Woodward Govern	c	618	43	93.000	7329	0.000	03/10/87	0.000	0.000	2078.899	0

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MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Waukesha	L7042G	858	r		c	583	45	92.300	3123	0.000	05/27/87	0.000	0.000	885.851	0
Waukesha	L7042G	775	r	Engelhardt CC	c	630	53	91.600	7607	0.000	09/22/87	0.000	0.000	2157.755	0
Waukesha	L7042G	775	r	Engelhardt CC	c	764	50	93.500	3028	0.000	12/08/87	0.000	0.000	858.904	0
Waukesha	L7042G	775	r	Engelhardt CC	c	2417	166	93.100	558	0.000	03/22/88	0.000	0.000	158.279	0
Waukesha	L7042G	775	r	Engelhardt CC	c	2257	197	91.300	2175	0.000	06/29/88	0.000	0.000	616.947	0
Waukesha	L7042G	775	r	Englehard NSCR	c	71	10	87.000	*****	0.000	03/30/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	52	4	92.000	*****	0.000	06/05/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	626	5	99.000	1420	0.000	09/13/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	619	67	89.000	3500	0.000	12/12/89	0.100	0.000	0.000	592
Waukesha	L7042G	775	r	Englehard NSCR	c	640	46	93.000	3665	0.000	03/09/90	0.200	0.000	0.000	592
Ajax	DP230	230	l			8	8	0.000	174	********	09/24/87	17.600	********	311.091	0
Ajax	DP230	230	l			7	7	0.000	133	********	09/24/87	16.300	********	170.587	0
Waukesha	L7042G	858	r		c	1074	16	98.500	9980	15.000	02/04/87	0.010	4.236	2818.669	0
Waukesha	L7042G	858	r		c	691	18	97.400	1528	0.000	05/27/87	0.000	0.000	433.423	0
Waukesha	L7042G	775	r	Engelhardt CC	c	635	1	99.800	*****	0.000	10/19/87	0.000	0.000	3468.803	0
Waukesha	L7042G	775	r	Engelhardt CC	c	769	16	97.900	466	0.000	12/08/87	0.000	0.000	132.183	0
Waukesha	L7042G	775	r	Engelhardt CC	c	2563	56	97.800	710	0.000	03/22/88	0.000	0.000	201.394	0
Waukesha	L7042G	775	r	Engelhardt CC	c	1231	61	95.000	4790	0.000	06/29/88	0.000	0.000	1358.702	0
Waukesha	L7042G	775	r	Englehard NSCR	c	591	16	99.000	5550	0.000	03/30/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	448	8	98.000	9561	0.000	06/05/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	458	21	95.000	*****	0.000	09/13/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	513	5	99.000	*****	0.000	12/12/89	0.100	0.000	0.000	593
Waukesha	L7042G	775	r	Englehard NSCR	c	565	38	93.000	6332	0.000	03/05/90	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	425	6	99.000	*****	0.000	04/09/90	0.100	0.000	0.000	594
Waukesha	L7042G	858	r	Woodward Govern	m	596	18	97.000	8957	0.000	03/10/87	0.000	0.000	2540.688	0
Waukesha	L7042G	858	r		m	597	55	90.800	5300	0.000	05/27/87	0.000	0.000	1503.365	0
Waukesha	L7042G	775	r	Engelhardt CC	m	641	18	97.200	5714	0.000	09/22/87	0.000	0.000	1620.798	0
Waukesha	L7042G	775	r	Engelhardt CC	m	571	29	94.900	*****	0.000	12/08/87	0.000	0.000	3097.784	0
Waukesha	L7042G	775	r	Engelhardt CC	m	2014	227	88.700	8896	0.000	03/22/88	0.000	0.000	2523.385	0
Waukesha	L7042G	775	r	Engelhardt CC	m	2248	53	97.600	2774	0.000	06/29/88	0.000	0.000	786.856	0
Waukesha	L7042G	775	r	Englehard NSCR	m	513	12	97.000	8482	0.000	03/30/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	m	629	31	95.000	5475	0.000	06/30/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	m	669	14	98.000	1680	0.000	09/13/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	m	690	18	97.000	2800	0.000	12/12/89	0.100	0.000	0.000	591
Waukesha	L7042G	775	r	Englehard NSCR	m	452	37	91.000	*****	0.000	03/05/90	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	m	171	5	97.000	*****	0.000	03/09/90	0.100	0.000	0.000	599

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VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Waukesha	L7042G	775	r	Englehard NSCR	m	532	44	92.000	9310	0.000	04/09/90	0.100	0.000	0.000	593
Waukesha	L7042G	858	r	Woodward Govern	m	475	0	1.000	*****	0.000	03/10/87	0.000	0.000	4262.466	0
Waukesha	L7042G	858	r		m	338	3	99.100	*****	0.000	05/27/87	0.000	0.000	3900.240	0
Waukesha	L7042G	775	r	Engelhardt CC	m	357	3	99.200	*****	0.000	09/22/87	0.000	0.000	5997.293	0
Waukesha	L7042G	775	r	Engelhardt CC	m	353	0	1.000	*****	0.000	12/08/87	0.000	0.000	6040.409	0
Waukesha	L7042G	775	r	Engelhardt CC	m	720	7	99.000	*****	0.000	03/22/88	0.000	0.000	9020.476	0
Waukesha	L7042G	775	r	Engelhardt CC	m	913	1	99.900	*****	0.000	06/29/88	0.000	0.000	8788.731	0
Waukesha	L7042G	775	r	Englehard NSCR	m	202	1	99.000	*****	0.000	03/30/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	m	157	1	99.000	*****	0.000	06/05/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	m	179	2	99.000	*****	0.000	09/13/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	m	191	2	99.000	*****	0.000	12/12/89	0.100	0.000	0.000	596
Waukesha	L7042G	858	r	Woodward Govern	m	180	0	1.000	*****	0.000	03/10/87	0.000	0.000	9631.466	0
Waukesha	L7042G	858	r		m	512	8	98.400	6700	0.000	05/28/87	0.000	0.000	1900.481	0
Waukesha	L7042G	775	r	Engelhardt CC	m	335	6	98.200	*****	0.000	09/22/87	0.000	0.000	5997.293	0
Waukesha	L7042G	775	r	Engelhardt CC	m	283	1	99.600	*****	0.000	12/08/87	0.000	0.000	6607.716	0
Waukesha	L7042G	775	r	Engelhardt CC	m	1342	24	98.200	*****	0.000	03/22/88	0.000	0.000	4779.567	0
Waukesha	L7042G	775	r	Engelhardt CC	m	879	4	99.500	*****	0.000	06/29/88	0.000	0.000	9018.774	0
Waukesha	L7042G	775	r	Englehard NSCR	m	144	3	97.000	*****	0.000	03/30/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	m	135	1	99.000	*****	0.000	06/05/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	m	163	4	98.000	*****	0.000	09/13/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	m	154	4	98.000	*****	0.000	12/12/89	0.100	0.000	0.000	595
Waukesha	L7042G	775	r	Englehard NSCR	m	674	33	94.000	3041	0.000	03/05/90	0.200	0.000	0.000	0
Waukesha	L7042G	858	r	Woodward Govern	c	345	38	89.000	*****	0.000	03/10/87	0.000	0.000	6686.288	0
Waukesha	L7042G	858	r		c	677	2	99.700	2137	0.000	05/28/87	0.000	0.000	606.168	0
Waukesha	L7042G	775	r	Engelhardt CC	c	531	8	98.500	9950	0.000	09/22/87	0.000	0.000	2822.356	0
Waukesha	L7042G	775	r	Engelhardt CC	c	766	17	97.800	789	0.000	12/08/87	0.000	0.000	223.803	0
Waukesha	L7042G	775	r	Engelhardt CC	c	2094	35	98.300	3825	0.000	03/22/88	0.000	0.000	1084.976	0
Waukesha	L7042G	775	r	Engelhardt CC	c	2114	30	98.600	2480	0.000	06/29/88	0.000	0.000	703.462	0
Waukesha	L7042G	775	r	Englehard NSCR	c	394	6	98.000	*****	0.000	03/31/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	380	7	98.000	*****	0.000	06/05/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	285	10	96.000	*****	0.000	09/13/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	439	7	99.000	8985	0.000	12/12/89	0.100	0.000	0.000	592
Waukesha	L7042G	775	r	Englehard NSCR	c	699	17	97.000	2513	0.000	03/09/90	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	410	11	97.000	*****	0.000	03/09/90	0.100	0.000	0.000	595
Waukesha	L7042G	858	r		m	1614	2	99.900	*****	63.000	02/06/87	0.010	17.793	4534.442	0
Waukesha	L7042G	858	r		m	773	1	99.900	213	0.000	05/29/87	0.000	0.000	60.418	0

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MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Waukesha	L7042G	775	r	Engelhardt CC	m	494	2	99.600	*****	0.000	09/22/87	0.000	0.000	10825.370	0
Waukesha	L7042G	775	r	Engelhardt CC	m	539	1	99.800	*****	0.000	12/08/87	0.000	0.000	4101.635	0
Waukesha	L7042G	775	r	Engelhardt CC	m	2589	3	99.900	*****	0.000	03/22/88	0.000	0.000	5829.087	0
Waukesha	L7042G	775	r	Engelhardt CC	m	2562	16	99.400	4340	0.000	06/29/88	0.000	0.000	1231.058	0
Waukesha	L7042G	775	r	Englehard NSCR	m	489	1	99.000	*****	0.000	03/31/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	m	493	6	99.000	*****	0.000	06/30/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	m	385	3	99.000	*****	0.000	09/14/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	m	409	13	97.000	*****	0.000	12/12/89	0.100	0.000	0.000	595
Waukesha	L7042G	775	r	Englehard NSCR	m	477	1	99.000	281	0.000	03/09/90	1.300	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	m	559	1	99.000	*****	0.000	03/09/90	0.100	0.000	0.000	596
Waukesha	L7042G	858	r	Woodward Govern	c	235	11	95.300	*****	0.000	03/10/87	0.000	0.000	9662.385	0
Waukesha	L7042G	858	r		c	333	27	91.900	*****	0.000	05/29/87	0.000	0.000	6085.226	0
Waukesha	L7042G	775	r	Engelhardt CC	c	280	18	93.600	*****	0.000	09/22/87	0.000	0.000	10825.370	0
Waukesha	L7042G	775	r	Engelhardt CC	c	255	23	91.000	*****	0.000	12/08/87	0.000	0.000	7488.462	0
Waukesha	L7042G	775	r	Engelhardt CC	c	717	57	92.100	*****	0.000	03/22/88	0.000	0.000	7516.827	0
Waukesha	L7042G	775	r	Engelhardt CC	c	780	37	95.300	*****	0.000	06/29/88	0.000	0.000	8396.154	0
Waukesha	L7042G	775	r	Englehard NSCR	c	144	3	98.000	*****	0.000	03/31/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	116	6	95.000	*****	0.000	06/05/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	103	5	95.000	*****	0.000	09/14/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	127	11	91.000	*****	0.000	12/28/89	0.400	0.000	0.000	597
Waukesha	L7042G	775	r	Englehard NSCR	c	560	47	91.000	7489	0.000	03/09/90	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	498	21	96.000	*****	0.000	04/09/90	0.100	0.000	0.000	594
Waukesha	L7042G	775	r	Englehard NSCR	c	0	15	91.900	5000	0.000	06/06/90	0.010	0.000	1410.000	594
Waukesha	L7042G	513	r		c	970	8	99.200	*****	42.000	02/24/87	0.010	11.862	4164.739	0
Waukesha	L7042G	858	r		c	839	3	99.600	201	0.000	05/29/87	0.000	0.000	57.014	0
Waukesha	L7042G	775	r	Engelhardt CC	c	620	20	96.800	4750	0.000	09/22/87	0.000	0.000	1347.356	0
Waukesha	L7042G	775	r	Engelhardt CC	c	694	22	96.800	2738	0.000	12/08/87	0.000	0.000	776.644	0
Waukesha	L7042G	775	r	Engelhardt CC	c	2147	43	98.000	6480	0.000	03/22/88	0.000	0.000	1838.077	0
Waukesha	L7042G	775	r	Engelhardt CC	c	2338	45	98.100	7556	0.000	06/29/88	0.000	0.000	2143.288	0
Waukesha	L7042G	775	r	Englehard NSCR	c	495	21	96.000	1735	0.000	03/31/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	337	11	97.000	*****	0.000	06/05/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	363	12	97.000	*****	0.000	09/14/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	372	17	96.000	*****	0.000	12/28/89	0.200	0.000	0.000	593
Waukesha	L7042G	775	r	Englehard NSCR	c	442	9	98.000	*****	0.000	03/05/90	0.100	0.000	0.000	595
Waukesha	L7042G	775	r	Englehard NSCR	c	360	20	94.000	*****	0.000	04/09/90	0.200	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	407	13	96.700	5000	0.000	06/06/90	0.010	0.000	1410.000	595

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VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Waukesha	L7042G	858	r		c	1204	5	99.600	*****	74.000	02/09/87	0.010	20.900	3247.401	0
Waukesha	L7042G	858	r		c	691	11	98.400	3806	0.000	05/29/87	0.000	0.000	1079.587	0
Waukesha	L7042G	775	r	Engelhardt CC	c	576	15	97.400	4021	0.000	09/22/87	0.000	0.000	1140.572	0
Waukesha	L7042G	775	r	Engelhardt CC	c	714	6	99.200	390	0.000	12/08/87	0.000	0.000	110.625	0
Waukesha	L7042G	775	r	Engelhardt CC	c	2432	150	93.800	4000	0.000	03/22/88	0.000	0.000	1134.615	0
Waukesha	L7042G	775	r	Engelhardt CC	c	2189	28	98.700	8874	0.000	06/29/88	0.000	0.000	2517.144	0
Waukesha	L7042G	775	r	Englehard NSCR	c	252	12	95.000	*****	0.000	03/31/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	210	5	97.000	*****	0.000	06/05/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	185	2	99.000	*****	0.000	09/14/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	c	254	4	98.000	*****	0.000	12/28/89	0.100	0.000	0.000	595
Waukesha	L7042G	775	r	Englehard NSCR	c	243	15	94.000	*****	0.000	03/05/90	0.200	0.000	0.000	597
Waukesha	L7042G	775	r	Englehard NSCR	c	565	44	91.000	2576	0.000	04/09/90	0.200	0.000	0.000	0
Waukesha	L7042G	858	r		m	950	3	99.700	9896	170.000	02/10/87	0.400	48.927	2848.117	0
Waukesha	L7042G	775	r	Engelhardt CC	m	668	21	96.900	679	0.000	09/22/87	0.000	0.000	192.601	0
Waukesha	L7042G	775	r	Engelhardt CC	m	660	10	98.500	6098	0.000	12/08/87	0.000	0.000	1729.721	0
Waukesha	L7042G	775	r	Engelhardt CC	m	2206	59	97.300	4120	0.000	03/22/88	0.000	0.000	1168.654	0
Waukesha	L7042G	775	r	Engelhardt CC	m	1922	42	97.800	*****	0.000	06/29/88	0.000	0.000	3797.558	0
Waukesha	L7042G	775	r	Englehard NSCR	m	464	32	93.000	*****	0.000	03/31/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	m	213	12	94.000	*****	0.000	06/05/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	m	865	14	94.000	*****	0.000	09/14/89	0.100	0.000	0.000	0
Waukesha	L7042G	775	r	Englehard NSCR	m	472	15	97.000	6564	0.000	12/28/89	0.100	0.000	0.000	591
Waukesha	L7042G	775	r	Englehard NSCR	m	497	27	95.000	*****	0.000	03/05/90	0.100	0.000	0.000	594
Waukesha	L7042G	775	r	Englehard NSCR	m	505	32	94.000	*****	0.000	04/09/90	0.100	0.000	0.000	0
Tecogen	CM-60	80	r		e	0	246	0.000	247	0.000	05/31/89	4.200	0.000	0.000	136
Tecogen	C-60	87	r	None	e	0	192	0.000	264	35.000	09/20/89	3.860	12.000	92.000	0
Tecogen	C-60	87	r	None	e	0	165	0.000	306	28.000	09/20/89	3.660	9.650	105.000	0
Ingersoll-Rand	SVG-12	660	r	Cat Control		537	6	98.900	3600	110.000	02/09/82	0.100	31.202	1021.154	0
Waukesha	L7042GU	1250	r	MEI Cat Muffler	c	711	23	96.800	*****	135.000	12/11/87	0.100	38.293	3118.207	0
Waukesha	L7042GU	1250	r	Cat Conv	c	1799	84	95.300	0	0.000	02/22/88	0.000	0.000	0.000	0
Waukesha	L7042GU	1250	r	Cat Conv	c	426	28	93.400	0	0.000	08/01/88	0.000	0.000	0.000	0
Waukesha	L7042GU	1250	r	NSCR	c	564	42	92.530	*****	75.200	10/07/89	0.010	53.630	3808.900	0
Waukesha	L7042GU	1250	r	NSCR	c	676	62	90.680	*****	135.800	08/06/90	0.070	101.000	3979.000	757
Waukesha	L7042GU	1250	r	NSCR	c	497	18	96.400	3189	116.000	07/29/92	0.040	33.000	902.000	548
Waukesha	L7042GU	1250	r	MEI Cat Muffler	c	572	39	93.200	*****	131.000	12/01/87	0.100	37.159	3566.380	0
Waukesha	L7042GU	1250	r	Cat Conv	c	2005	114	94.300	0	0.000	02/22/88	0.000	0.000	0.000	0
Waukesha	L7042GU	1250	r	Cat Conv	c	318	26	91.800	0	0.000	08/02/88	0.000	0.000	0.000	0

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VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Waukesha	L7042GU	1250	r	NSCR	c	215	40	81.395	0	0.000	03/22/89	0.030	0.000	0.000	518
Waukesha	L7042GU	1250	r	NSCR	c	613	44	92.840	*****	104.000	10/06/89	0.010	77.250	3681.400	0
Waukesha	L7042GU	1250	r	NSCR	c	554	31	94.280	7947	79.000	08/06/90	0.010	56.000	2244.000	582
Waukesha	L7042GU	1250	r	NSCR	c	694	44	93.700	2643	84.000	07/29/92	0.040	23.840	748.000	575
Waukesha	L7042GU	1250	r	MEI Cat Muffler	c	67	7	89.600	*****	307.000	12/01/87	0.100	87.082	10668.790	0
Waukesha	L7042GU	1250	r	Cat Conv	c	635	56	91.200	0	0.000	02/22/88	0.000	0.000	0.000	0
Waukesha	L7042GU	1250	r	Cat Conv	c	841	12	98.600	0	0.000	08/02/88	0.000	0.000	0.000	0
Waukesha	L7042GU	1250	r	NSCR	c	845	49	94.201	4460	0.000	03/23/89	0.010	0.000	1257.000	517
Waukesha	L7042GU	1250	r	NSCR	c	793	18	97.670	2522	78.000	08/06/90	0.010	53.000	712.000	741
Waukesha	L7042GU	1250	r	NSCR	c	598	30	94.900	*****	107.000	07/29/92	0.050	30.000	3544.000	594
Waukesha	L5790GU	748	r	ESC	c	391	49	87.430	*****	54.000	10/06/89	0.030	32.700	4115.200	0
Waukesha	L5790GU	748	r	ESC	c	322	28	91.080	7917	84.000	08/09/90	0.010	51.800	2236.000	728
Waukesha	L5790GU	748	r	ECS NSCR	c	571	46	92.000	9963	70.000	07/27/92	0.040	19.860	2818.000	728
Waukesha	L5790GU	748	r	ESC Model 45	c	588	31	94.660	8648	8.800	10/02/89	0.010	4.180	2442.700	0
Waukesha	L5790GU	748	r	ESC Model 45	c	622	52	92.540	*****	86.000	08/09/90	0.020	53.300	4013.000	749
Waukesha	L5790GU	748	r	ECS NSCR	c	782	65	91.700	*****	43.000	07/27/92	0.060	12.000	2836.000	766
Cooper Bessemer	GMV	660	l	NergasGNA deNOx	d	304	151	50.300	0	0.000	10/23/87	0.000	0.000	0.000	0
Cooper Bessemer	GMV	660	l	NergasGNA deNOx	d	170	170	0.000	0	0.000	08/04/88	0.000	0.000	0.000	0
Caterpillar	G342	225	r	ECS Cat Conv	c	436	2	99.500	*****	93.000	12/19/87	0.100	26.380	4991.173	0
Caterpillar	G342	225	r	ECS Cat Conv	c	443	13	97.100	0	0.000	08/03/88	0.000	0.000	0.000	0
Caterpillar	G342	225	r	ESC NSCR	c	618	17	97.200	3211	0.000	10/04/89	0.070	0.000	909.500	0
Caterpillar	G342	225	r	ESC NSCR	c	566	15	97.360	7353	37.000	08/09/90	0.380	26.300	2113.850	205
Caterpillar	G342	225	r	ECS NSCR	c	395	1	99.500	*****	110.000	07/28/92	0.120	31.200	3183.400	186
Ingersoll-Rand	SVG-12	660	r	ECS Lo Nox 44	d	443	1	99.800	*****	18.600	12/03/86	0.010	5.253	3384.380	0
Ingersoll-Rand	SVG-12	660	r	ECS Cat Conv	d	116	7	94.000	0	0.000	08/04/88	0.000	0.000	0.000	0
Ingersoll-Rand	SVG-12	660	r	NSCR	d	587	25	95.660	7222	4.000	10/04/89	0.010	2.550	2039.400	0
Ingersoll-Rand	SVG-12	660	r	ECS Lo NOx 44	d	501	4	99.200	*****	22.300	12/02/86	0.010	6.298	3065.515	0
Ingersoll-Rand	SVG-12	660	r	ECS Cat Conv	d	260	16	93.800	0	0.000	10/22/87	0.000	0.000	0.000	0
Ingersoll-Rand	SVG-12	660	r	ECS Cat Conv	d	162	3	98.100	0	0.000	08/04/88	0.000	0.000	0.000	0
Ingersoll-Rand	SVG-12	660	r	NSCR	d	546	29	94.750	7400	25.100	10/05/89	0.070	16.000	2096.000	0
Ingersoll-Rand	SVG-12	660	r	ECS Lo NOx 44		461	4	99.100	*****	18.000	12/01/86	0.100	5.106	3804.933	0
Ingersoll-Rand	SVG-12	660	r	ECS Cat Conv		565	4	99.300	0	0.000	10/22/87	0.000	0.000	0.000	0
Ingersoll-Rand	SVG-12	660	r	ECS Lo NOx 44		519	4	99.200	9053	22.500	11/24/86	0.200	6.413	2580.324	0
Worthington	58-2	1000	l	None		425	425	0.000	410	166.100	12/11/86	9.600	86.725	214.071	0
Worthington	58-2	1000	l	None		195	195	0.000	331	81.900	12/12/86	11.000	48.809	197.263	0
Worthington	58-2	1000	l			52	52	0.000	0	0.000	10/21/87	0.000	0.000	0.000	0

Table D-2

VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Ingersoll-Rand	SVG-12	660	r	ECS Lo NOx 44	d	514	19	96.300	9383	30.500	12/03/86	0.010	8.614	2650.057	0
Ingersoll-Rand	SVG-12	660	r	ECS Cat Conv	d	73	4	94.500	0	0.000	10/23/87	0.000	0.000	0.000	0
Ingersoll-Rand	SVG-12	660	r	ECS Cat Conv	d	321	18	94.400	0	0.000	08/12/88	0.000	0.000	0.000	0
Ingersoll-Rand	SVG-12	660	r	NSCR	d	389	48	87.550	*****	37.500	10/05/89	0.020	23.900	3124.700	0
Ingersoll-Rand	SVG-12	660	r	ECS Lo NOx 44	d	393	4	99.000	*****	25.800	12/03/86	0.100	7.318	5174.413	0
Ingersoll-Rand	SVG-12	660	r	ECS Cat Conv	d	778	10	98.700	0	0.000	10/23/87	0.000	0.000	0.000	0
Ingersoll-Rand	SVG-12	660	r	ECS Cat Conv	d	278	13	95.300	0	0.000	08/09/88	0.000	0.000	0.000	0
Worthington	58-2	950	l	None		151	151	0.000	339	291.200	12/11/86	11.500	182.774	212.777	0
Worthington	58-2	1000	l			96	96	0.000	0	0.000	10/20/87	0.000	0.000	0.000	0
Ingersoll-Rand	SVG-12	660	r	EngelhardTorvex		449	3	99.300	4050	357.000	02/09/82	0.050	101.022	1146.043	0
Ingersoll-Rand	SVG-12	660	r	EngelhardTorvex		315	8	97.500	*****	22.400	12/12/86	0.100	6.354	5932.620	0
Ingersoll-Rand	SVG-12	660	r	ECS Lo NOx 44	d	461	0	1.000	*****	22.300	12/02/86	0.010	6.298	3752.671	0
Ingersoll-Rand	SVG-12	660	r	ECS Cat Conv	d	626	42	93.300	0	0.000	10/20/87	0.000	0.000	0.000	0
Ingersoll-Rand	SVG-12	660	r	ECS Cat Conv	d	182	10	94.500	0	0.000	08/04/88	0.000	0.000	0.000	0
Ingersoll-Rand	SVG-12	660	r	NSCR	d	512	19	96.330	8533	23.800	10/05/89	0.050	14.800	2415.000	0
Ingersoll-Rand	SVG-12	660	r	ECS Cat Conv		747	23	96.900	0	0.000	10/20/87	0.000	0.000	0.000	0
Ingersoll-Rand	SVG-12	660	r	ECS Cat Conv	d	981	10	99.000	0	0.000	10/20/87	0.000	0.000	0.000	0
Ingersoll-Rand	SVG-12	660	r	ECS Cat Conv	d	406	38	90.600	0	0.000	08/05/88	0.000	0.000	0.000	0
Ingersoll-Rand	SVG-12	660	r	NSCR	d	715	28	96.140	2567	1.500	10/04/89	0.010	0.850	725.000	0
Ingersoll-Rand	SVG-12	660	r	ECS Lo NOx 44	d	426	19	95.500	*****	20.000	12/01/86	0.100	5.673	4474.639	0
Ingersoll-Rand	SVG-12	660	r	ECS Cat Conv	d	157	6	96.200	0	0.000	08/05/88	0.000	0.000	0.000	0
Ingersoll-Rand	SVG-12	660	r	NSCR	d	503	40	92.080	4775	28.800	10/05/89	0.010	18.120	1348.000	0
Worthington	58-2	950	l	None		151	151	0.000	308	206.400	12/11/86	11.100	124.261	185.429	0
Worthington	58-2	1000	l			136	136	0.000	0	0.000	10/20/87	0.000	0.000	0.000	0
Ingersoll-Rand	SVG-12	660	r	ECS Lo NOx 44		758	3	99.600	9990	20.800	11/24/86	0.100	5.900	2833.702	0
White Superior	G-8258	625	r	ECS Lo NOx 44	c	478	19	96.000	*****	17.000	12/04/86	0.010	4.801	3954.045	0
White Superior	G-8258	625	r	ECS Cat Conv	c	324	38	88.300	0	0.000	10/19/87	0.000	0.000	0.000	0
White Superior	G-8258	625	r	ECS Cat Conv	c	507	36	92.900	0	0.000	08/03/88	0.000	0.000	0.000	0
White	G-8258	625	r	NSCR	c	390	39	89.980	*****	21.000	10/02/89	0.050	13.130	3798.400	0
White	G-8258	625	r	NSCR	c	333	35	89.360	7967	33.750	08/09/90	0.010	23.560	2250.000	717
White	G-8258	625	r	NSCR	c	666	18	97.400	*****	14.600	07/28/92	0.030	4.120	3682.200	667
White Superior	G-8258	625	r	ECS Lo NOx 44	c	497	22	95.600	*****	22.500	12/04/86	0.010	6.355	3883.437	0
White Superior	G-8258	625	r	ECS Cat Conv	c	108	12	88.900	0	0.000	10/19/87	0.000	0.000	0.000	0
White Superior	G-8258	625	r	ECS Cat Conv	c	248	2	99.200	0	0.000	08/03/88	0.000	0.000	0.000	0
White	G-8258	625	r	HIS	c	268	8	97.015	*****	0.000	03/23/89	0.010	0.000	6704.000	800
White	G-8258	625	r	HIS	c	451	46	89.860	*****	18.200	10/02/89	0.010	11.180	4055.400	0

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VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
White	G-8258	625	r	HIS	c	1765	2	99.510	5162	31.000	08/09/90	0.010	18.860	1457.000	651
White	G-8258	625	r	HIS	c	1052	1	99.630	9203	29.000	08/15/90	0.010	17.000	2598.000	651
White	G-8258	625	r	HIS	c	362	12	96.600	9121	25.000	07/28/92	0.110	7.210	2588.600	672
Waukesha		74	r	None-ERC		339	339	0.000	2191	123.500	09/10/87	0.280	35.337	626.911	0
Waukesha		74	r	None - ERC		189	189	0.000	2183	318.000	09/10/87	0.470	91.836	630.431	0
Waukesha		74	r	None - ERC		247	247	0.000	2665	201.000	09/10/87	0.510	58.161	771.138	0
White Superior	G-8258	625	r	ECS Lo NOx 44	d	306	27	91.200	*****	20.400	12/05/86	0.100	5.787	5375.240	0
White Superior	G-8258	625	r	ECS Cat Conv	d	165	27	83.600	0	0.000	10/21/87	0.000	0.000	0.000	0
White Superior	G-8258	625	r	ECS Cat Conv	d	596	50	91.600	0	0.000	08/05/88	0.000	0.000	0.000	0
White Superior	G-8258	625	r	ECS Lo NOx 44	d	369	24	93.500	*****	18.700	12/05/86	0.100	5.304	4806.514	0
White Superior	G-8258	625	r	ECS Cat Conv	d	117	22	81.200	0	0.000	10/21/87	0.000	0.000	0.000	0
White Superior	G-8258	625	r	ECS Cat Conv	d	326	29	91.100	0	0.000	08/05/88	0.000	0.000	0.000	0
White Superior	G-8258	625	r	ECS Lo NOx 44	d	585	47	92.000	*****	18.100	12/05/86	0.100	5.134	3332.933	0
White Superior	G-8258	625	r	ECS Cat Conv	d	154	39	74.700	0	0.000	10/21/87	0.000	0.000	0.000	0
White Superior	G-8258	625	r	ECS Cat Conv	d	303	23	92.400	0	0.000	08/05/88	0.000	0.000	0.000	0
Ingersoll-Rand	XVG	300	r	PSC PreStrat Ch	c	79	79	0.000	61	0.000	04/16/88	0.000	0.000	27.685	0
Ingersoll-Rand	XVG	300	r	PSC PreStrat Ch	c	17	17	0.000	159	0.000	05/24/88	0.000	0.000	72.162	0
Ingersoll-Rand	XVG	300	r	PSC PreStrat Ch	c	28	28	0.000	137	0.000	09/14/88	0.000	0.000	62.177	0
Ingersoll-Rand	XVG	300	r	PSC PreStrat Ch	c	67	67	0.000	212	52.000	12/21/88	7.900	23.600	96.215	0
Ingersoll-Rand	XVG	300	r	PSC PreStrat Ch	c	814	20	97.543	0	0.000	02/22/89	7.800	0.000	0.000	0
Ingersoll-Rand	XVG	300	r	PSC	c	814	44	94.600	0	0.000	05/17/89	6.600	0.000	0.000	673
Ingersoll-Rand	XVG	300	r	PSC	c	814	45	94.400	186	0.000	09/20/89	6.590	0.000	0.000	623
Ingersoll-Rand	XVG	300	r	PSC	c	814	67	91.800	180	0.000	12/13/89	7.000	0.000	0.000	352
Ingersoll-Rand	XVG	300	r	PSC	c	814	31	96.200	288	0.000	03/20/90	7.600	0.000	0.000	340
Ingersoll-Rand	XVG	300	r	PSC	c	814	52	93.700	217	0.000	07/17/90	7.800	0.000	0.000	525
Ingersoll-Rand	XVG	300	r	PSC	c	814	14	98.340	196	0.000	09/24/91	8.900	0.000	0.000	668
Ingersoll-Rand	XVG	300	r	PSC	c	814	72	91.200	170	0.000	12/03/91	9.200	0.000	0.000	596
Ingersoll-Rand	SVG-8	440	r	PSC PreStrat Ch	c	86	86	0.000	176	0.000	04/15/88	0.000	0.000	76.353	0
Ingersoll-Rand	SVG-8	440	r	PSC PreStrat Ch	c	69	69	0.000	160	0.000	05/24/88	0.000	0.000	69.412	0
Ingersoll-Rand	SVG-8	440	r	PSC PreStrat Ch	c	70	70	0.000	160	0.000	09/14/88	0.000	0.000	69.412	0
Ingersoll-Rand	SVG-8	440	r	PSC PreStrat Ch	c	78	78	0.000	184	82.800	12/21/88	7.300	35.921	79.824	0
Ingersoll-Rand	SVG-8	440	r	PSC PreStrat Ch	c	1261	67	94.687	0	0.000	02/22/89	7.300	0.000	0.000	0
Ingersoll-Rand	SVG-8	440	r	PSC	c	1261	94	92.500	0	0.000	05/18/89	9.100	0.000	0.000	865
Ingersoll-Rand	SVG-8	440	r	PSC	c	1261	87	93.100	137	0.000	09/20/89	8.000	0.000	0.000	784
Ingersoll-Rand	XVG	300	r	PSC PreStrat Ch	c	79	79	0.000	85	0.000	04/15/88	0.000	0.000	42.863	0
Ingersoll-Rand	XVG	300	r	PSC PreStrat Ch	c	41	41	0.000	94	0.000	05/24/88	0.000	0.000	47.402	0

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VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Ingersoll-Rand	XVG	300	r	PSC PreStrat Ch	c	10	10	0.000	138	0.000	09/14/88	0.000	0.000	69.590	0
Ingersoll-Rand	XVG	300	r	PSC PreStrat Ch	c	53	53	0.000	199	14.000	12/21/88	9.200	7.060	100.350	0
Ingersoll-Rand	XVG	300	r	PSC PreStrat Ch	c	1429	34	97.621	0	0.000	02/22/89	9.200	0.000	0.000	0
Ingersoll-Rand	XVG	300	r	PSC	c	1429	58	95.900	0	0.000	05/17/89	8.800	0.000	0.000	540
Ingersoll-Rand	XVG	300	r	PSC	c	1429	37	97.400	249	0.000	09/20/89	8.650	0.000	0.000	464
Ingersoll-Rand	XVG	300	r	PSC	c	1429	77	95.000	191	0.000	12/13/89	7.200	0.000	0.000	309
Ingersoll-Rand	XVG	300	r	PSC	c	1429	45	96.900	276	0.000	07/17/90	8.300	0.000	0.000	536
Ingersoll-Rand	XVG	300	r	PSC	c	1429	46	96.750	391	0.000	09/24/91	8.800	0.000	0.000	644
Ingersoll-Rand	XVG	300	r	PSC	c	1429	97	93.200	555	0.000	12/03/91	9.150	0.000	0.000	507
Ingersoll-Rand	XVG	300	r	PSC	c	991	19	98.100	177	0.000	03/19/90	11.200	0.000	0.000	751
Ingersoll-Rand	XVG	300	r	PSC	c	991	93	90.100	153	0.000	07/17/90	13.100	0.000	0.000	881
Ingersoll-Rand	XVG	300	r	PSC	c	991	62	93.750	202	0.000	09/24/91	10.000	0.000	0.000	712
Ingersoll-Rand	XVG	300	r	PSC	c	991	50	94.900	306	0.000	12/03/91	10.300	0.000	0.000	526
Ingersoll-Rand	XVG	300	r	PSC PreStrat Ch	c	68	68	0.000	108	0.000	04/16/88	0.000	0.000	49.395	0
Ingersoll-Rand	XVG	300	r	PSC PreStrat Ch	c	81	81	0.000	93	0.000	05/24/88	0.000	0.000	42.535	0
Ingersoll-Rand	XVG	300	r	PSC PreStrat Ch	c	21	21	0.000	152	0.000	09/14/88	0.000	0.000	69.519	0
Ingersoll-Rand	XVG	300	r	PSC PreStrat Ch	c	34	34	0.000	184	28.800	12/21/88	8.400	13.594	86.848	0
Ingersoll-Rand	XVG	300	r	PSC PreStrat Ch	c	1090	26	97.615	0	0.000	02/22/89	7.800	0.000	0.000	0
Ingersoll-Rand	XVG	300	r	PSC	c	1090	22	97.900	0	0.000	05/17/89	7.800	0.000	0.000	583
Ingersoll-Rand	XVG	300	r	PSC	c	1090	68	93.800	152	0.000	09/20/89	7.700	0.000	0.000	608
Ajax	DCP-180	180	l	Clean Burn	c	51	51	0.000	102	********	08/07/87	13.600	********	82.438	0
Ajax	DCP-180	180	l	Clean Burn	c	0	60	0.000	0	0.000	05/17/89	13.500	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	38	0.000	116	0.000	09/19/89	13.200	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	38	0.000	83	0.000	12/12/89	15.900	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	42	0.000	0	0.000	03/20/90	13.300	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	33	0.000	111	680.000	06/14/90	13.300	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	40	0.000	124	307.000	09/23/91	13.200	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	78	78	0.000	170	0.000	07/03/86	0.000	0.000	126.962	0
Ajax	DCP-180	180	l	Clean Burn	c	51	51	0.000	144	0.000	10/02/86	0.000	0.000	107.544	0
Ajax	DCP-180	180	l	Clean Burn	c	35	35	0.000	177	0.000	02/09/87	0.000	0.000	132.190	0
Ajax	DCP-180	180	l	Clean Burn	c	56	56	0.000	150	0.000	04/23/87	0.000	0.000	112.025	0
Ajax	DCP-180	180	l	Clean Burn	c	55	55	0.000	131	990.000	08/06/87	13.000	739.367	97.835	0
Ajax	DCP-180	180	l	Clean Burn	c	50	50	0.000	150	0.000	04/18/88	0.000	0.000	128.261	0
Ajax	DCP-180	180	l	Clean Burn	c	44	44	0.000	0	0.000	06/10/88	0.000	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	25	25	0.000	129	0.000	09/13/88	0.000	0.000	110.304	0
Ajax	DCP-180	180	l	Clean Burn	c	84	84	0.000	158	75.300	12/01/88	14.900	74.045	155.367	0

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VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Ajax	DCP-180	180	l	Clean Burn	c	57	57	0.000	0	0.000	02/21/89	14.000	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	60	0.000	0	0.000	05/17/89	14,800	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	38	0.000	106	0.000	09/19/89	13.700	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	71	0.000	125	0.000	12/12/89	14.400	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	37	0.000	0	0.000	03/20/90	13.600	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	38	0.000	134	775.000	06/14/90	14.200	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	25	0.000	113	275.000	09/23/91	13.700	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	49	49	0.000	227	0.000	07/02/86	0.000	0.000	227.000	0
Ajax	DCP-180	180	l	Clean Burn	c	28	28	0.000	195	0.000	10/02/86	0.000	0.000	195.000	0
Ajax	DCP-180	180	l	Clean Burn	c	39	39	0.000	113	0.000	01/09/87	0.000	0.000	113.000	0
Ajax	DCP-180	180	l	Clean Burn	c	28	28	0.000	155	0.000	04/22/87	0.000	0.000	155.000	0
Ajax	DCP-180	180	l	Clean Burn	c	53	53	0.000	129	862.000	08/06/87	14.200	759.075	113.597	0
Ajax	DCP-180	180	l	Clean Burn	c	78	78	0.000	159	0.000	04/18/88	0.000	0.000	159.000	0
Ajax	DCP-180	180	l	Clean Burn	c	60	60	0.000	0	0.000	06/10/88	0.000	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	18	18	0.000	133	0.000	09/13/88	0.000	0.000	133.000	0
Ajax	DCP-180	180	l	Clean Burn	c	44	44	0.000	154	129.000	12/01/88	15.400	138.382	165.200	0
Ajax	DCP-180	180	l	Clean Burn	c	61	61	0.000	0	0.000	02/21/89	15.400	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	55	0.000	0	0.000	05/17/89	13.100	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	32	0.000	172	0.000	09/19/89	13.800	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	38	0.000	165	0.000	12/12/89	13.200	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	45	0.000	156	********	06/14/90	14.700	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	41	0.000	0	0.000	03/20/90	14.200	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	45	0.000	176	674.000	09/23/91	13.100	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	30	30	0.000	106	0.000	07/02/86	0.000	0.000	90.638	0
Ajax	DCP-180	180	l	Clean Burn	c	18	18	0.000	103	0.000	10/02/86	0.000	0.000	88.072	0
Ajax	DCP-180	180	l	Clean Burn	c	46	46	0.000	119	0.000	01/09/87	0.000	0.000	101.754	0
Ajax	DCP-180	180	l	Clean Burn	c	30	30	0.000	119	0.000	04/22/87	0.000	0.000	101.754	0
Ajax	DCP-180	180	l	Clean Burn	c	60	60	0.000	110	768.000	08/07/87	14.600	719.238	103.016	0
Ajax	DCP-180	180	l	Clean Burn	c	35	35	0.000	165	0.000	04/18/88	0.000	0.000	141.087	0
Ajax	DCP-180	180	l	Clean Burn	c	28	28	0.000	0	0.000	06/10/88	0.000	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	21	21	0.000	93	0.000	09/13/88	0.000	0.000	79.522	0
Ajax	DCP-180	180	l	Clean Burn	c	45	45	0.000	159	23.200	12/01/88	15.500	25.348	173.722	0
Ajax	DCP-180	180	l	Clean Burn	c	28	28	0.000	0	0.000	02/21/89	13.200	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	38	0.000	0	0.000	05/17/89	12.700	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	45	0.000	128	0.000	09/19/89	13.630	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	38	0.000	156	0.000	12/12/89	13.700	0.000	0.000	0

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VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Ajax	DCP-180	180	l	Clean Burn	c	0	27	0.000	0	0.000	03/20/90	14.000	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	61	0.000	141	********	06/14/90	15.100	0.000	0.000	0
Ajax	DCP-180	180	l	Clean Burn	c	0	30	0.000	219	679.000	09/23/91	13.700	0.000	0.000	0
Ajax	K-6700D	180	l		d	54	54	0.000	153	0.000	06/24/86	0.000	0.000	153.000	0
Ajax	DCP-140	140	l	Unknown-Clean?	c	0	68	0.000	348	153.000	09/19/90	14.860	0.000	339.450	0
Ajax	DCP-140	140	l		c	0	6	0.000	456	631.000	07/13/92	13.700	518.000	374.000	395
Minneapolis-Mol	800-6A	80	r	NSCR		0	6	0.000	582	15.000	07/13/92	0.010	4.280	164.400	30
Minneapolis-Mol	800-6A	80	r	NSCR	c	0	13	0.000	199	102.850	07/13/92	0.050	29.000	56.240	45
Minneapolis-Mol	800-6A	80	r	NSCR	c	0	6	0.000	1999	4.400	06/23/92	0.010	1.230	564.000	0
Waukesha	H2476G	186	r	NSCR	c	749	47	93.740	2400	400.000	09/20/89	0.030	113.000	678.000	0
Waukesha	F1197GU	186	r	NSCR	c	992	53	94.670	1346	265.000	05/23/90	0.030	74.900	380.500	0
Waukesha	F1197GU	186	r	NSCR	c	575	23	96.000	4330	0.000	03/10/92	0.160	0.000	1232.000	0
Waukesha	H2476G	186	r	NSCR	c	655	38	94.170	4800	590.000	09/19/89	0.030	167.000	1357.000	0
Waukesha	F1197GU	186	r	NSCR	c	684	45	93.430	1443	370.000	05/22/90	0.020	104.500	407.700	0
Waukesha	F1197GU	186	r	NSCR	c	660	41	94.000	3343	0.000	03/10/92	0.090	0.000	948.000	0
Waukesha	H2476G	186	r	NSCR	c	714	46	93.620	1900	485.000	09/19/89	0.040	137.000	537.000	0
Waukesha	F1197GU	186	r	NSCR	c	647	17	97.340	4331	430.000	05/22/90	0.030	122.000	1224.000	0
Waukesha	F1197GU	186	r	NSCR	c	612	37	94.000	3043	0.000	03/11/92	0.070	0.000	862.000	0
Superior	8GTLB	1100	l	Clean Burn	c	0	13	0.000	567	********	05/24/90	11.500	********	356.000	0
Superior	8GTLB	1100	l	Clean Burn	c	0	11	0.000	650	0.000	03/12/92	12.000	0.000	431.000	0
Superior	8GTLB	1100	l	Clean Burn	c	0	32	0.000	450	********	05/24/90	10.830	********	264.000	0
Superior	8GTLB	1100	l	Clean Burn	c	0	19	0.000	443	0.000	03/12/92	11.380	0.000	274.000	0
Superior	8GTLB	1100	l	Clean Burn	c	0	23	0.000	436	********	05/23/90	10.780	********	254.000	0
Superior	8GTLB	1100	l	Clean Burn	c	0	17	0.000	402	0.000	03/12/92	11.200	0.000	245.000	0
Tecogen	CM-60	80	r	None	e	0	223	0.000	257	0.000	04/12/89	4.800	0.000	0.000	149
Caterpillar	G398	412	r	Cat Converter	c	475	31	93.500	*****	228.000	04/26/88	0.010	64.394	4397.745	0
Caterpillar	G398	412	r	Cat Converter	c	271	37	86.300	*****	0.000	04/26/88	0.000	0.000	8662.221	0
Caterpillar	G398	412	r	NS Cat Conv.	c	628	17	97.300	8015	0.000	07/27/88	0.000	0.000	2273.486	0
Caterpillar	G398	412	r	PSC PreStrat Ch	c	492	45	90.900	600	790.000	12/28/87	8.800	385.207	292.562	0
Caterpillar	G398	412	r	PSC Turbo	c	787	46	94.100	436	0.000	01/30/89	7.830	0.000	197.000	0
Caterpillar	G398	412	r	PSC PreStrat Ch	c	787	46	94.155	435	0.000	01/30/89	7.800	0.000	195.916	0
Caterpillar	G398	412	r	PSC PreStrat Ch	c	677	43	93.648	665	185.600	03/03/89	8.100	85.550	306.523	0
Ingersoll-Rand	XVG	300	r	catalyst		311	3	99.000	*****	17.000	12/31/85	0.100	4.822	8055.769	0
Ingersoll-Rand	XVG	300	r	catalyst		57	22	61.404	*****	104.000	12/07/88	0.100	29.500	13606.310	0
Ingersoll-Rand	XVG	300	r	JohnsonMatthey	s	306	1	99.700	*****	62.000	12/23/87	0.010	17.511	5583.394	0
Ingersoll-Rand	XVG	300	r	JohnsonMatthey	s	277	10	96.390	*****	0.000	03/17/88	0.000	0.000	6308.114	0

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VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Ingersoll-Rand	XVG	300	r	JohnsonMatthey	s	129	41	68.217	*****	0.000	06/13/88	0.000	0.000	8716.127	0
Ingersoll-Rand	XVG	300	r	JohnsonMatthey	s	92	18	80.435	*****	0.000	09/16/88	0.000	0.000	12091.750	0
Ingersoll-Rand	XVG-8	300	r	catalyst	d	64	17	73.400	*****	63.500	03/19/86	0.100	18.012	22438.720	0
Ingersoll-Rand	XVG-8	300	r	catalyst	d	26	15	42.300	*****	0.000	06/16/86	0.000	0.000	14341.820	0
Ingersoll-Rand	XVG-8	300	r	JohnsonMatthey	d	77	1	98.700	*****	0.000	09/25/86	0.000	0.000	9502.404	0
Ingersoll-Rand	XVG-8	300	r	JohnsonMatthey	d	149	2	98.700	*****	23.200	12/10/86	0.010	6.552	9461.465	0
Ingersoll-Rand	XVG-8	300	r	JohnsonMatthey	d	412	2	99.500	*****	0.000	03/04/87	0.000	0.000	3886.058	0
Ingersoll-Rand	XVG-8	300	r	JohnsonMatthey	d	337	16	95.300	*****	0.000	09/30/87	0.000	0.000	2873.981	0
Ingersoll-Rand	XVG-8	300	r	JohnsonMatthey	d	277	35	87.400	*****	33.000	01/08/88	0.010	9.361	4725.366	0
Ingersoll-Rand	XVG	300	r	JohnsonMatthey	d	90	39	56.667	*****	0.000	03/18/88	0.000	0.000	10867.630	0
Ingersoll-Rand	XVG	300	r	JohnsonMatthey	d	105	27	74.286	*****	0.000	06/17/88	0.000	0.000	10642.980	0
Ingersoll-Rand	XVG	300	r	JohnsonMatthey	d	109	5	95.413	*****	0.000	09/16/88	0.000	0.000	9905.760	0
Ingersoll-Rand	XVG	300	r		d	334	1	100.000	8033	********	11/08/89	0.100	373.000	2268.000	253
Waukesha	L7042GL	1100	l	Clean Burn	c	73	73	0.000	594	173.700	03/16/87	9.700	91.503	312.911	0
Waukesha	L7042GL	1100	l	Clean Burn	c	45	45	0.000	539	129.800	03/27/87	10.000	70.259	291.752	0
Waukesha	L7042GL	1100	l	Clean Burn	c	41	41	0.000	521	150.400	03/27/87	10.000	81.409	282.009	0
Waukesha	L7042GL	1100	l	Clean Burn	c	56	56	0.000	579	75.600	03/27/87	10.000	40.921	313.404	0
Waukesha	L7042GL	1100	l	Clean Burn	c	47	47	0.000	427	0.000	06/16/87	0.000	0.000	231.128	0
Waukesha	L7042GL	1164	l	Clean Burn	c	125	125	0.000	484	0.000	09/28/87	0.000	0.000	261.982	0
Waukesha	L7042GL	959	l	Clean Burn	c	87	87	0.000	574	0.000	01/15/88	0.000	0.000	310.697	0
Waukesha	L7042GL	984	l	Clean Burn	c	98	98	0.000	568	198.000	03/31/88	10.200	109.178	313.196	0
Waukesha	L7042GL	1100	l	Clean Burn	c	77	77	0.000	623	0.000	07/14/88	0.000	0.000	337.220	0
Waukesha	L7042GL	1100	l	Clean Burn	c	63	63	0.000	585	0.000	09/21/88	0.000	0.000	316.651	0
Waukesha	L7042GL	1100	l	Clean Burn	c	45	45	0.000	517	233.000	03/13/89	10.200	128.477	285.075	0
Waukesha	L7042GL	1100	l	Clean Burn	c	0	60	0.000	588	0.000	06/14/89	9.800	0.000	0.000	1831
Waukesha	L7042GL	1100	l	Clean Burn	c	0	53	0.000	500	0.000	09/20/89	9.500	0.000	263.000	2001
Waukesha	L7042GL	1100	l	Clean Burn	c	0	56	0.000	462	0.000	11/29/89	9.600	0.000	248.000	1894
Waukesha	L7042GL	1100	l	Clean Burn	c	0	46	0.000	528	204.000	02/27/90	10.600	117.000	302.000	1992
Waukesha	L7042GL	1100	l	Clean Burn	c	45	45	0.000	525	287.700	03/16/87	10.200	158.638	289.486	0
Waukesha	L7042GL	1100	l	Clean Burn	c	67	67	0.000	474	0.000	06/16/87	0.000	0.000	282.485	0
Waukesha	L7042GL	1235	l	Clean Burn	c	55	55	0.000	451	0.000	09/28/87	0.000	0.000	268.778	0
Waukesha	L7042GL	1005	l	Clean Burn	c	104	104	0.000	500	0.000	01/15/88	0.000	0.000	297.980	0
Waukesha	L7042GL	941	l	Clean Burn	c	92	92	0.000	505	187.000	03/31/88	10.400	105.076	283.762	0
Waukesha	L7042GL	1100	l	Clean Burn	c	136	136	0.000	610	0.000	09/21/88	0.000	0.000	363.535	0
Waukesha	L7042GL	1100	l	Clean Burn	c	60	60	0.000	500	0.000	03/13/89	10.200	0.000	275.701	0
Waukesha	L7042GL	1100	l	Clean Burn	c	0	42	0.000	465	0.000	06/14/89	10.500	0.000	0.000	2056

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VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Waukesha	L7042GL	1100	l	Clean Burn	c	0	48	0.000	404	230.000	09/20/89	10.000	125.000	209.000	2057
Waukesha	L7042GL	1100	l	Clean Burn	c	0	104	0.000	470	0.000	11/29/89	10.100	0.000	243.000	1958
Waukesha	L7042GL	1108	l	Clean Burn	c	0	36	0.000	466	0.000	09/05/90	10.600	0.000	267.000	2037
Waukesha	L7042GL	1100	l	Clean Burn	c	54	54	0.000	554	189.600	03/18/87	10.300	105.532	308.358	0
Waukesha	L7042GL	1100	l	Clean Burn	c	40	40	0.000	438	0.000	06/16/87	0.000	0.000	261.030	0
Waukesha	L7042GL	1120	l	Clean Burn	c	45	45	0.000	443	0.000	10/08/87	0.000	0.000	264.010	0
Waukesha	L7042GL	1067	l	Clean Burn	c	98	98	0.000	508	0.000	01/18/88	0.000	0.000	302.747	0
Waukesha	L7042GL	987	l	Clean Burn	c	84	84	0.000	513	171.000	03/31/88	10.200	94.290	282.869	0
Waukesha	L7042GL	1062	l	Clean Burn	c	63	63	0.000	542	0.000	07/14/88	0.000	0.000	323.010	0
Waukesha	L7042GL	1100	l	Clean Burn	c	61	61	0.000	525	0.000	09/21/88	0.000	0.000	312.879	0
Waukesha	L7042GL	1100	l	Clean Burn	c	72	72	0.000	521	197.000	03/13/89	9.500	101.956	269.640	0
Waukesha	L7042GL	1100	l	Clean Burn	c	0	52	0.000	530	0.000	06/14/89	9.700	0.000	0.000	1966
Waukesha	L7042GL	1100	l	Clean Burn	c	0	85	0.000	569	0.000	09/20/89	9.100	0.000	280.000	2021
Waukesha	L7042GL	1100	l	Clean Burn	c	0	93	0.000	494	0.000	11/29/89	9.500	0.000	256.000	1899
Waukesha	L7042GL	1108	l	Clean Burn	c	0	119	0.000	593	0.000	06/05/90	9.200	0.000	292.000	2143
Waukesha	L7042GL	1108	l	Clean Burn	c	0	31	0.000	512	0.000	09/05/90	10.400	0.000	288.000	1973
Waukesha	L7042GL	1108	l	Clean Burn	c	0	69	0.000	592	107.000	12/02/91	9.600	56.000	301.000	1914
Waukesha	L7042GL	1100	l	Clean Burn	c	44	44	0.000	520	239.400	03/18/87	10.300	133.251	289.434	0
Waukesha	L7042GL	1100	l	Clean Burn	c	47	47	0.000	468	0.000	06/16/87	0.000	0.000	278.909	0
Waukesha	L7042GL	1058	l	Clean Burn	c	84	84	0.000	450	0.000	10/08/87	0.000	0.000	268.182	0
Waukesha	L7042GL	979	l	Clean Burn	c	173	173	0.000	556	0.000	01/18/88	0.000	0.000	331.354	0
Waukesha	L7042GL	964	l	Clean Burn	c	88	88	0.000	507	169.000	03/31/88	10.100	92.324	276.972	0
Waukesha	L7042GL	1100	l	Clean Burn	c	90	90	0.000	611	0.000	03/13/89	9.300	0.000	310.767	0
Waukesha	L7042GL	1100	l	Clean Burn	c	0	52	0.000	480	0.000	09/20/89	9.800	0.000	255.000	2008
Waukesha	L7042GL	1100	l	Clean Burn	c	0	115	0.000	541	206.000	11/29/89	9.700	113.000	275.000	1864
Waukesha	L7042GL	1100	l	Clean Burn	c	0	48	0.000	556	0.000	02/27/90	10.000	0.000	285.000	1945
Waukesha	L7042GL	1108	l	Clean Burn	c	0	28	0.000	147	0.000	06/05/90	9.100	0.000	74.000	1749
Waukesha	L7042GL	1108	l	Clean Burn	c	0	57	0.000	605	0.000	09/05/90	10.100	0.000	331.000	1980
Ingersoll-Rand	SVG-10	500	r	Dupont 22-19PR5		432	61	85.900	9300	0.000	04/02/82	0.000	0.000	2637.981	0
Ingersoll-Rand	SVG-10	550	r	catalyst		260	17	93.500	*****	0.000	06/16/86	0.000	0.000	5386.587	0
Ingersoll-Rand	SVG-10	550	r	JohnsonMatthey		42	1	97.600	*****	0.000	08/28/86	0.000	0.000	14721.630	0
Ingersoll-Rand	SVG-10	550	r	JohnsonMatthey		180	1	99.400	*****	0.000	12/09/86	0.000	0.000	4651.923	0
Waukesha	F3521GL	616	l	Clean Burn	c	0	34	0.000	544	255.000	05/07/90	9.800	135.000	294.000	976
Waukesha	F3521GL	616	l	Clean Burn	c	0	35	0.000	530	224.000	05/07/90	9.700	121.000	282.000	1006
Ingersoll-Rand	XVG	300	r	EngelhardTorvex	d	298	7	97.700	*****	38.000	12/23/87	0.100	10.779	4722.553	0
Ingersoll-Rand	XVG	300	r	EngelhardTorvex	d	196	3	98.469	*****	0.000	02/26/88	0.000	0.000	5632.798	0

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VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Ingersoll-Rand	XVG	300	r	EnglehardTorvex	d	431	9	97.912	5912	0.000	06/13/88	0.000	0.000	1676.962	0
Ingersoll-Rand	XVG	300	r	EngelhardTorvex	d	304	13	95.724	*****	0.000	09/14/88	0.000	0.000	3556.452	0
Ingersoll-Rand	XVG	300	r	EnglehardTorvex	d	245	5	97.959	*****	55.000	12/07/88	0.100	15.601	4593.207	0
Ingersoll-Rand	XVG-8	300	r	NSCR	d	479	100	79.000	*****	0.000	06/07/89	0.100	0.000	8036.000	0
Ingersoll-Rand	XVG	300	r	JohnsonMatthey	s	404	3	99.300	*****	44.000	12/23/87	0.010	12.427	3352.748	0
Ingersoll-Rand	XVG	300	r	JohnsonMatthey	s	359	4	98.886	8966	0.000	03/01/88	0.000	0.000	2543.240	0
Ingersoll-Rand	XVG	300	r	JohnsonMatthey	s	139	32	76.978	*****	0.000	06/13/88	0.000	0.000	8769.726	0
Ingersoll-Rand	XVG	300	r	JohnsonMatthey	s	39	28	28.205	*****	0.000	09/14/88	0.000	0.000	14141.850	0
Ingersoll-Rand	XVG	300	r	JohnsonMatthey	s	43	1	97.674	*****	0.000	12/14/88	0.100	0.000	21939.490	0
Ingersoll-Rand	XVG-8	300	r	NSCR	s	520	84	84.000	*****	70.000	06/07/89	0.100	20.000	8725.000	250
Ingersoll-Rand	XVG	300	r	NSCR	s	100	40	60.000	*****	0.000	11/08/89	0.100	0.000	11160.000	0
Ingersoll-Rand	XVG	300	r	EngelhardTorvex	s	407	2	99.500	*****	44.000	12/30/87	0.010	12.427	3642.240	0
Ingersoll-Rand	XVG	300	r	EngelhardTorvex	s	260	6	97.692	*****	0.000	02/26/88	0.000	0.000	5451.543	0
Ingersoll-Rand	XVG	300	r	EngelhardTorvex	s	127	1	99.213	*****	0.000	06/17/88	0.000	0.000	8607.476	0
Ingersoll-Rand	XVG	300	r	EngelhardTorvex	s	242	14	94.215	*****	0.000	12/06/88	0.100	0.000	5967.510	0
Ingersoll-Rand	XVG	300	r		s	217	43	80.300	*****	0.000	09/01/89	0.200	0.000	7400.000	0
Ingersoll-Rand	XVG	300	r		s	276	22	92.000	*****	0.000	11/09/89	0.100	0.000	6082.000	0
Ingersoll-Rand	XVG	300	r	EngelhardTorvex	s	259	5	98.100	*****	33.000	12/31/87	0.010	9.320	5528.037	0
Ingersoll-Rand	XVG	300	r	EngelhardTorvex	s	357	6	98.319	*****	0.000	03/17/88	0.000	0.000	3349.385	0
Ingersoll-Rand	XVG	300	r	EngelhardTorvex	s	216	4	98.148	*****	0.000	06/17/88	0.000	0.000	5888.087	0
Ingersoll-Rand	XVG	300	r	EngelhardTorvex	s	226	6	97.345	*****	0.000	09/14/88	0.000	0.000	6045.514	0
Ingersoll-Rand	XVG	300	r	EngelhardTorvex	s	103	3	97.087	*****	45.000	12/06/88	0.100	12.764	10612.340	0
Ingersoll-Rand	XVG-8	300	r	NSCR	s	746	61	92.000	*****	0.000	06/23/89	0.100	0.000	7934.000	0
Ingersoll-Rand	XVG	300	r		s	79	22	72.500	*****	0.000	09/01/89	0.100	0.000	11252.000	0
Ingersoll-Rand	XVG	300	r		s	369	25	93.000	*****	40.000	11/09/89	0.100	11.000	4377.000	317
Ingersoll-Rand	XVG-8	300	r	NSCR	s	0	30	0.000	1669	45.000	12/05/91	0.200	13.000	476.000	101
Ingersoll-Rand	SVG-10	550	r	catalyst	s	169	5	97.000	*****	41.300	03/19/86	0.400	11.886	21119.410	0
Ingersoll-Rand	SVG-10	550	r	catalyst	s	153	2	98.700	*****	0.000	06/18/86	0.000	0.000	6705.577	0
Ingersoll-Rand	SVG-10	550	r		s	272	1	99.600	*****	0.000	09/11/86	0.000	0.000	6694.231	0
Ingersoll-Rand	SVG-10	550	r	JohnsonMatthey	s	65	1	98.500	*****	128.900	12/09/86	0.200	36.740	13909.180	0
Ingersoll-Rand	SVG-10	550	r	JohnsonMatthey	s	344	13	96.200	*****	0.000	02/18/87	0.000	0.000	10208.990	0
Ingersoll-Rand	SVG-10	550	r	JohnsonMatthey	s	91	7	92.300	*****	0.000	06/09/87	0.000	0.000	6042.678	0
Ingersoll-Rand	SVG-10	550	r	JohnsonMatthey	s	142	9	93.700	*****	0.000	09/18/87	0.000	0.000	7014.380	0
Ingersoll-Rand	SVG-10	550	r	JohnsonMatthey	s	283	30	89.400	*****	70.000	12/29/87	0.010	19.770	4766.036	0
Ingersoll-Rand	SVG-10	550	r	JohnsonMatthey	s	67	12	82.090	*****	0.000	02/26/88	0.000	0.000	12378.090	0
Ingersoll-Rand	SVG-10	550	r	JohnsonMatthey	s	69	20	71.014	*****	0.000	06/13/88	0.000	0.000	13685.730	0

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VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Ingersoll-Rand	SVG-10	550	r	JohnsonMatthey	s	69	23	66.667	*****	0.000	09/14/88	0.000	0.000	13960.880	0
Ingersoll-Rand	XVG	300	r	JohnsonMatthey	s	58	25	56.897	*****	115.000	12/06/88	0.300	32.937	13468.900	0
Ingersoll-Rand	SVG-10	550	r	JMI NSCR	s	365	1	99.000	*****	0.000	06/23/89	0.100	0.000	9246.000	0
Ingersoll-Rand	XVG	550	r		s	103	1	99.200	*****	0.000	09/06/89	0.100	0.000	11277.000	0
Ingersoll-Rand	XVG	550	r		s	390	1	99.200	*****	36.000	11/09/89	0.100	10.000	3546.000	383
Ingersoll-Rand	SVG-10	550	r	JMI NSCR	s	0	3	0.000	139	6.000	12/16/91	0.200	2.000	40.000	143
Waukesha	L5790GU	738	r	EngelhardTorvex	c	183	3	98.400	7641	12.000	09/18/87	0.400	3.454	2199.117	0
Waukesha	L5790GU	738	r	Engelhard Cat	c	479	1	99.800	*****	0.000	01/15/88	0.010	0.000	6976.065	0
Waukesha	L5790GU	738	r	Engelhard Cat	c	245	1	99.592	3785	0.000	06/23/88	0.000	0.000	1073.630	0
Waukesha	L5790GU	738	r	Engelhard Cat	c	102	1	99.020	*****	0.000	09/09/88	0.000	0.000	5187.462	0
Waukesha	L5790GU	738	r	EngelhardTorvex	c	164	3	98.171	*****	0.000	11/14/88	0.100	0.000	5111.159	0
Waukesha	L5790GU	738	r	NSCR	c	592	3	99.493	*****	0.000	06/21/89	0.100	0.000	9020.000	0
Waukesha	L5790GU	738	r	NSCR	c	328	12	96.900	9437	48.000	08/31/89	0.100	13.000	2664.000	432
Waukesha	L5790GU	738	r	NSCR	c	415	2	100.000	*****	0.000	11/17/89	0.100	0.000	2865.000	0
Waukesha	L5790GU	738	r	NSCR	c	224	6	97.500	*****	0.000	06/20/90	0.100	0.000	5477.000	0
Waukesha	L5790GU	738	r	NSCR	c	0	17	0.000	6855	0.000	12/02/91	0.200	0.000	1935.000	0
Waukesha	L5790GU	738	r	NSCR	c	0	65	0.000	6671	176.000	03/11/92	0.100	50.000	1883.000	0
Waukesha	F1197GU	150	r	EngelhardTorvex	c	747	39	94.800	3913	39.000	11/10/87	0.010	11.015	1105.156	0
Waukesha	F1197GU	98	r	EngelhardTorvex	c	146	44	69.863	*****	0.000	02/17/88	0.000	0.000	10848.990	0
Waukesha	F1197GU	150	r	EngelhardTorvex	c	90	33	63.333	*****	155.000	08/22/88	0.700	45.272	13722.170	0
Waukesha	F1197GU	150	r	EnglehardTorvex	c	102	7	93.137	*****	0.000	01/31/89	0.100	0.000	9698.692	0
Waukesha	F1197GU	150	r	Englehard	c	104	23	79.000	*****	0.000	06/08/89	0.700	0.000	11712.000	0
Waukesha	F1197GU	150	r	Englehard	c	95	3	97.300	*****	121.000	09/07/89	0.200	35.000	12230.000	155
Waukesha	F1197GU	150	r	Englehard	c	177	25	85.600	*****	0.000	11/16/89	0.300	0.000	11610.000	0
Waukesha	F1197GU	150	r	Englehard NSCR	c	154	29	81.000	*****	0.000	02/20/90	0.100	0.000	10319.000	0
Waukesha	F1187GU	150	r	JM NSCR	c	225	15	93.300	*****	0.000	05/15/90	0.100	0.000	4288.000	0
Waukesha	F1197GU	150	r	Englehard NSCR	c	489	11	97.900	1386	12.000	10/03/90	0.100	3.000	391.000	165
Waukesha	F1197GU	150	r	Englehard	c	0	2	0.000	1596	13.000	12/10/91	0.100	4.000	453.000	45
Waukesha	F1197GU	150	r	Englehard	c	190	47	75.400	*****	133.000	12/13/91	0.200	38.000	3911.000	101
Waukesha	F1197GU	150	r	Englehard NSCR	c	0	4	0.000	944	552.000	06/04/92	4.100	194.000	332.000	54
Waukesha	F1197GU	150	r	Englehard NSCR		0	11	0.000	300	284.000	06/04/92	0.100	80.000	127.000	38
Waukesha	F1197GU	150	r	Catalyst	c	351	17	95.200	9700	23.400	10/28/86	0.010	6.609	2739.588	0
Waukesha	F1197GU	150	r	JohnsonMatthey	c	35	20	42.900	*****	0.000	02/19/87	0.000	0.000	14332.570	0
Waukesha	F1197GU	150	r	JohnsonMatthey	c	221	13	94.100	5769	0.000	09/30/87	0.000	0.000	1629.349	0
Waukesha	F1197GU	150	r	JM Denox 250	c	62	20	67.700	5949	10.000	01/19/88	3.300	3.352	1994.267	0
Waukesha	F1197GU	150	r	JohnsonMatthey	c	141	13	90.780	*****	0.000	03/18/88	0.000	0.000	9969.575	0

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VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Waukesha	F1197GU	150	r	JohnsonMatthey	c	76	35	53.947	*****	0.000	09/08/88	0.200	0.000	14101.860	0
Waukesha	F1197GU	150	r	JohnsonMatthey	c	168	7	95.833	*****	0.000	02/14/89	0.200	0.000	12305.350	0
Waukesha	F1197GU	150	r	JM NSCR	c	102	11	87.000	*****	0.000	06/19/89	1.100	0.000	5556.000	0
Waukesha	F1197GU	150	l	JM NSCR	c	205	5	97.700	*****	0.000	09/08/89	0.600	0.000	3450.000	0
Waukesha	F1197GU	150	r	JM NSCR	c	271	15	94.000	*****	89.000	11/30/89	0.700	26.000	3946.000	185
Waukesha	F1197GU	150	r	JM NSCR	c	0	41	0.000	*****	0.000	02/28/90	0.700	0.000	3958.000	0
Waukesha	F1197GU	150	r	JM NSCR	c	201	31	84.500	*****	0.000	05/21/90	1.000	0.000	4435.000	0
Waukesha	F1197GU	150	r	JM NSCR	c	194	31	84.000	*****	0.000	08/29/90	0.800	0.000	3399.000	0
Waukesha	F1197GU	150	r	JM NSCR	c	0	18	0.000	6154	30.000	12/10/91	0.700	9.000	1797.000	45
Waukesha	F1197GU	150	r	JM NSCR	c	0	27	0.000	2317	408.000	06/05/92	4.000	142.000	809.000	55
Waukesha	F1197GU	150	r	Catalyst	c	572	29	94.900	8000	23.200	10/28/86	0.010	6.552	2259.454	0
Waukesha	F1197GU	150	r	JohnsonMatthey	c	64	34	46.900	*****	0.000	02/19/87	0.000	0.000	9249.641	0
Waukesha	F1197GU	150	r	JohnsonMatthey	c	107	23	78.500	8487	0.000	09/30/87	0.000	0.000	2396.999	0
Waukesha	F1197GU	150	r	JM Denox 250	c	87	35	59.800	*****	131.000	01/19/88	0.900	38.645	6721.280	0
Waukesha	F1197GU	150	r	JohnsonMatthey	c	119	32	73.109	*****	0.000	03/18/88	0.000	0.000	12826.940	0
Waukesha	F1197GU	150	r	JohnsonMatthey	c	117	12	89.744	*****	0.000	09/08/88	0.300	0.000	7706.374	0
Waukesha	F1197GU	150	r	JohnsonMatthey	c	120	16	86.667	*****	22.300	02/17/89	0.400	6.418	9129.746	0
Waukesha	F1197GU	150	r	JM NSCR	c	79	19	77.000	8213	0.000	06/19/89	3.600	0.000	2807.000	0
Waukesha	F1197GU	150	r	JM NSCR	c	75	12	84.600	*****	0.000	09/08/89	0.100	0.000	10014.000	0
Waukesha	F1197GU	150	r	JM NSCR	c	106	5	94.800	*****	0.000	05/21/90	0.400	0.000	4505.000	0
Waukesha	F1197GU	150	r	JM NSCR	c	88	7	91.600	5907	72.000	08/29/90	5.500	28.000	2263.000	274
Waukesha	F1197GU	150	r	JM NSCR	c	36	9	75.600	7677	9.000	12/13/91	4.100	3.000	2696.000	125
Waukesha	F1197GU	150	r	JM NSCR	c	0	35	0.000	813	349.000	06/05/92	5.400	133.000	309.000	60
Waukesha	F1197GU	150	r	EngelhardTorvex	c	265	5	98.100	*****	24.000	01/19/88	0.100	6.808	5828.803	0
Waukesha	F1197GU	150	r	EngelhardTorvex	c	236	35	85.169	*****	0.000	03/30/88	0.000	0.000	7924.242	0
Waukesha	F1197GU	150	r	EngelhardTorvex	c	142	30	78.873	*****	0.000	09/08/88	0.100	0.000	11969.060	0
Waukesha	F1197GU	150	r	EngelhardTorvex	c	486	19	96.091	9958	0.000	02/14/89	0.100	0.000	2824.625	0
Waukesha	F1197GU	150	r	Englehard NSCR	c	247	28	89.000	*****	0.000	06/19/89	0.100	0.000	8662.000	0
Waukesha	F1197GU	150	r	Englehard NSCR	c	101	12	88.300	*****	0.000	11/30/89	0.300	0.000	8396.000	0
Waukesha	F1197GU	150	r	Englehard NSCR	c	0	10	0.000	4733	22.000	02/28/90	0.100	6.000	1560.000	271
Waukesha	F1197GU	150	r	Englehard NSCR	c	304	14	95.500	*****	0.000	05/21/90	0.100	0.000	4380.000	0
Waukesha	F1197GU	150	r	Englehard NSCR	c	303	16	94.700	8589	0.000	08/29/90	0.100	0.000	2425.000	0
Waukesha	F1197GU	150	r	Englehard NSCR	c	0	14	0.000	1619	0.000	12/10/91	1.000	0.000	480.000	0
Waukesha	F1197GU	150	r	Englehard NSCR	c	0	45	0.000	2607	710.000	06/05/92	2.400	133.000	831.000	50
Waukesha	F1197GU	150	r	JohnsonMatthey		63	27	57.100	*****	0.000	06/11/87	0.000	0.000	5219.783	0
Waukesha	145GKU	90	r	EngelhardTorvex	d	312	2	99.400	9032	64.000	11/12/87	0.300	18.330	2586.835	0

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VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Waukesha	145GKU	65	r	EngelhardTorvex	d	389	1	99.743	5192	0.000	02/18/88	0.000	0.000	1487.029	0
Waukesha	145GKU	90	r	Englehard	d	517	5	99.000	5477	0.000	06/15/89	0.100	0.000	1550.000	0
Waukesha	145GKU	90	r	Englehard	d	99	5	95.200	*****	149.000	09/07/89	0.100	42.000	8606.000	247
Waukesha	145GKU	90	r	Englehard NSCR	d	174	8	95.100	*****	0.000	05/14/90	0.100	0.000	3226.000	0
Waukesha	145GKU	90	r	Englehard NSCR	d	143	3	97.900	5322	0.000	10/03/90	0.100	0.000	1502.000	0
Waukesha	145GKU	90	r	EngelhardTorvex	d	386	6	98.400	531	6.000	11/12/87	0.010	1.695	149.971	0
Waukesha	145GKU	65	r	EngelhardTorvex	d	457	19	95.842	1373	0.000	02/18/88	0.000	0.000	389.457	0
Waukesha	145GKU	90	r	EngelhardTorvex	d	421	9	97.862	1973	0.000	08/23/88	0.100	0.000	559.649	0
Waukesha	145GKU	90	r	EngelhardTorvex	d	515	31	93.981	7288	50.800	02/17/89	0.100	14.410	2067.269	0
Waukesha	145GKU	90	r	Englehard	d	404	28	93.000	*****	0.000	06/15/89	0.100	0.000	4373.000	0
Waukesha	145GKU	90	r	Englehard	d	465	26	94.500	*****	0.000	09/15/89	0.100	0.000	2929.000	0
Waukesha	145GKU	90	r	Englehard	d	430	16	96.200	*****	0.000	12/01/89	0.100	0.000	4295.000	0
Waukesha	145GKU	90	r	Engelhard	d	561	42	92.500	5596	28.000	02/22/90	0.300	8.000	1603.000	260
Ingersoll-Rand	SVG-6	330	r	catalyst	m	266	20	92.500	*****	28.100	03/20/86	0.200	8.009	5671.696	0
Ingersoll-Rand	SVG-6	330	r	catalyst	m	236	10	95.800	*****	0.000	06/09/86	0.000	0.000	4767.544	0
Ingersoll-Rand	SVG-6	330	r	Torvex	m	176	8	95.500	*****	0.000	08/27/86	0.000	0.000	7274.757	0
Ingersoll-Rand	SVG-6	330	r	Torvex	m	242	4	98.300	*****	20.600	12/10/86	0.010	5.818	4970.799	0
Ingersoll-Rand	SVG-6	330	r	Torvex	m	227	5	97.800	*****	0.000	02/26/87	0.000	0.000	4978.053	0
Ingersoll-Rand	SVG-6	330	r	JohnsonMatthey	m	201	5	97.500	*****	0.000	06/10/87	0.000	0.000	3459.507	0
Ingersoll-Rand	SVG-6	330	r	Torvex	m	412	13	96.800	8812	0.000	09/29/87	0.000	0.000	2523.825	0
Ingersoll-Rand	SVG-6	330	r	Torvex	m	562	10	98.200	2757	22.000	12/15/87	0.300	6.301	789.626	0
Ingersoll-Rand	SVG-6	330	r	EngelhardTorvex	m	318	16	94.969	*****	0.000	02/18/88	0.000	0.000	4083.316	0
Ingersoll-Rand	SVG-6	330	r	EngelhardTorvex	m	326	20	93.865	*****	0.000	08/23/88	0.100	0.000	7677.375	0
Ingersoll-Rand	SVG-6	330	r	EngelhardTorvex	m	332	7	97.892	*****	0.000	02/14/89	0.200	0.000	3305.140	0
Ingersoll-Rand	SVG-6	330	r	JMI NSCR	m	168	10	94.300	*****	0.000	09/07/89	0.500	0.000	6211.000	0
Ingersoll-Rand	SVG-6	330	r	JMI NSCR	m	417	11	97.400	1166	0.000	02/22/90	6.700	0.000	329.000	0
Ingersoll-Rand	SVG-6	330	r	JMI NSCR	m	245	10	95.900	*****	24.000	05/15/90	1.900	7.000	3400.000	419
Ingersoll-Rand	SVG-6	330	r	JMI NSCR	m	319	6	98.200	7996	29.000	10/19/90	0.100	9.000	2395.000	387
Waukesha	F1197GU	150	r	EngelhardTorvex		479	3	99.400	*****	10.000	11/10/87	0.700	2.921	3574.757	0
Ingersoll-Rand	SVG-6	330	r	catalyst	m	372	19	94.900	1299	2.600	04/07/86	0.100	0.738	368.466	0
Ingersoll-Rand	SVG-6	330	r	catalyst	m	355	7	98.000	8409	0.000	06/09/86	0.000	0.000	2385.245	0
Ingersoll-Rand	SVG-6	330	r		m	251	2	99.200	*****	0.000	08/28/86	0.000	0.000	5758.173	0
Ingersoll-Rand	SVG-6	330	r	JohnsonMatteny	m	372	1	99.700	*****	0.000	12/17/86	0.000	0.000	3347.115	0
Ingersoll-Rand	SVG-6	330	r	JohnsonMatthey	m	433	2	99.500	9383	22.200	03/19/87	0.010	6.270	2650.057	0
Ingersoll-Rand	SVG-6	330	r	JohnsonMatthey	m	342	6	98.200	4562	0.000	06/10/87	0.000	0.000	1294.029	0
Ingersoll-Rand	SVG-6	330	r	JohnsonMatthey	m	177	3	98.300	9440	0.000	09/29/87	0.000	0.000	2677.692	0

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VENTURA COUNTY APCD SOURCE TEST DATA

MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Ingersoll-Rand	SVG-6	330	r	JohnsonMatthey	m	373	21	94.400	1040	0.000	12/15/87	0.000	0.000	295.000	0
Ingersoll-Rand	SVG-6	330	r	JohnsonMatthey	m	358	4	98.883	9005	23.000	02/18/88	0.100	6.524	2554.303	0
Ingersoll-Rand	SVG-6	330	r	JohnsonMatthey	m	207	2	99.034	*****	0.000	08/23/88	0.100	0.000	5420.625	0
Ingersoll-Rand	SVG-6	330	r	EngelhardTorvex	m	263	3	98.859	8489	14.600	02/17/89	0.100	4.141	2407.938	0
Ingersoll-Rand	SVG-6	330	r	JM NSCR	m	142	10	93.000	*****	0.000	06/15/89	0.500	0.000	7105.000	0
Ingersoll-Rand	SVG-6	330	r		m	322	15	97.700	*****	0.000	11/30/89	0.100	0.000	4574.000	0
Ingersoll-Rand	SVG-6	330	r	JMI NSCR	m	307	11	96.500	9092	0.000	10/03/90	0.100	0.000	2567.000	0
Waukesha	F1197GU	98	r	EngelhardTorvex	c	488	8	98.361	5562	0.000	02/17/88	0.000	0.000	1577.683	0
Waukesha	F1197GU	150	r	EngelhardTorvex	c	231	14	93.939	*****	136.000	08/22/88	0.100	38.577	8926.870	0
Waukesha	F1197GU	150	r	EngelhardTorvex	c	436	27	93.807	9000	0.000	02/14/89	0.100	0.000	2552.885	0
Waukesha	F1197GU	150	r	Englehard	c	355	6	98.000	*****	0.000	06/08/89	0.100	0.000	2867.000	0
Waukesha	F1197GU	150	r	Englehard	c	90	17	81.100	*****	323.000	09/07/89	0.100	91.000	11408.000	173
Waukesha	F1197GU	150	r	Englehard	c	90	33	63.600	*****	0.000	11/16/89	0.100	0.000	15592.000	0
Waukesha	F1197GU	150	r	Englehard NSCR	c	68	48	30.200	*****	0.000	02/20/90	0.600	0.000	10414.000	0
Waukesha	F1197GU	150	r	Englehard	c	190	8	95.700	*****	0.000	05/15/90	0.100	0.000	3785.000	0
Waukesha	F1197GU	150	r	Englehard NSCR	c	481	18	96.200	2702	48.000	10/11/90	0.200	14.000	770.000	86
Waukesha	F1197GU	98	r	EngelhardTorvex	c	211	34	83.886	*****	0.000	02/17/88	0.000	0.000	7102.802	0
Waukesha	F1197GU	150	r	EngelhardTorvex	c	33	18	45.455	*****	272.000	08/22/88	0.200	77.527	12391.140	0
Waukesha	F1197GU	150	r	EngelhardTorvex	c	98	3	96.939	*****	0.000	01/31/89	0.100	0.000	7076.880	0
Waukesha	F1197GU	150	r	Englehard	c	31	9	68.000	*****	0.000	06/08/89	0.500	0.000	12037.000	0
Waukesha	F1197GU	150	r	Englehard	c	39	11	71.300	*****	146.000	09/07/89	0.100	41.000	12812.000	231
Waukesha	F1197GU	150	r	Englehard	c	40	18	55.300	*****	0.000	11/16/89	0.100	0.000	18123.000	0
Waukesha	F1197GU	150	r	Englehard NSCR	c	117	36	69.700	*****	0.000	02/20/90	0.100	0.000	5472.000	0
Waukesha	F1197GU	150	r	Englehard NSCR	c	62	38	38.100	*****	0.000	05/14/90	0.200	0.000	10033.000	0
Waukesha	F1197GU	150	r	Englehard NSCR	c	565	35	93.900	7025	28.000	10/11/90	0.200	11.000	2002.000	222
Waukesha	F1197GU	150	r	EngelhardTorvex		449	17	96.200	*****	19.000	11/10/87	0.010	5.366	3216.616	0
Waukesha	F1197GU	150	r	JohnsonMatthey		39	20	48.700	*****	0.000	06/11/87	0.000	0.000	7664.693	0
Clark	HRA-32	350	l		m	0	373	0.000	216	132.000	12/06/90	15.280	0.000	227.000	1320
Clark	HRA-32	350	l		m	0	194	0.000	176	122.000	12/06/90	14.430	0.000	160.000	1126
Clark	HRA-32	350	l	catalyst	m	220	67	69.500	485	0.000	04/28/86	0.000	0.000	485.000	0
Clark	HRA-32	350	l		m	259	90	65.300	460	0.000	08/27/86	0.000	0.000	460.000	0
Clark	HRA-32	350	l	Torvex Cat	m	238	39	83.600	410	269.700	12/17/86	13.100	204.004	310.128	0
Clark	HRA-32	350	l	Torvex	m	211	50	76.300	289	0.000	02/26/87	0.000	0.000	289.000	0
Clark	HRA-32	350	l	Torvex	m	293	52	82.300	208	0.000	06/11/87	0.000	0.000	208.000	0
Clark	HRA-32	350	l	Torvex Cat	m	556	111	80.000	214	0.000	10/08/87	0.000	0.000	214.000	0
Clark	HRA-32	350	l	Torvex	m	373	111	70.200	450	537.000	12/15/87	14.200	472.881	396.269	0

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MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Clark	HRA-32	350	l	Torvex Cat	m	303	63	79.208	273	0.000	03/30/88	0.000	0.000	273.000	0
Clark	HRA-32	350	l	EngelhardTorvex	m	314	75	76.115	365	0.000	09/09/88	14.900	0.000	358.917	0
Clark	HRA-32	350	l	EngelhardTorvex	m	199	61	69.347	374	0.000	03/15/89	14.800	0.000	361.738	0
Clark	HRA-32	350	l	Englehard SCR	m	161	55	67.000	190	0.000	06/16/89	14.200	0.000	167.000	0
Clark	HRA-32	350	l	Englehard SCR	m	336	100	70.200	452	0.000	10/30/89	12.700	0.000	325.000	0
Clark	HRA-32	350	l		m	0	243	0.000	164	0.000	05/26/89	13.900	0.000	138.000	0
Clark	HRA-32	350	l		m	0	79	0.000	209	90.000	12/06/90	15.010	0.000	209.000	1032
Clark	HRA-32	350	l		m	0	992	0.000	438	139.000	12/06/90	14.460	0.000	401.000	1572
Cooper Bessemer	GMV-8	800	l	Kleenaire	m	609	77	87.400	262	********	03/13/87	13.700	********	214.694	0
Cooper Bessemer	GMV-8	800	l	Kleenaire	m	818	108	86.800	524	0.000	06/10/87	0.000	0.000	429.389	0
Cooper Bessemer	GMV-8	800	l	Kleenaire	m	1100	83	92.500	300	434.000	08/03/87	10.900	256.060	177.000	0
Cooper Bessemer	GMV-8	800	l	Kleenaire	m	779	132	83.100	730	********	08/26/87	13.200	********	559.351	0
Cooper Bessemer	GMV-8	800	l	Kleenaire	m	660	98	85.200	527	0.000	01/08/88	13.500	0.000	420.176	0
Cooper Bessemer	GMV-8	800	l	Kleenaire	m	638	46	92.790	795	0.000	06/23/88	0.000	0.000	679.783	0
Cooper Bessemer	GMV-8	800	l	Kleenaire	m	576	38	93.403	1688	0.000	09/09/88	0.000	0.000	1443.362	0
Cooper Bessemer	GMV-8	800	r	Kleenaire	m	553	85	84.629	618	0.000	11/14/88	14.100	0.000	536.206	0
Cooper Bessemer	GMV-8	800	l	Nergas SCR	m	972	95	90.000	1535	595.000	06/22/89	11.700	381.000	986.000	1257
Cooper Bessemer	GMV-8	800	l	Nergas SCR	m	532	58	89.200	456	776.000	03/02/90	12.600	551.000	324.000	3984
Cooper Bessemer	GMV-8	800	l	Nergas SCR	m	0	45	0.000	560	0.000	06/20/90	12.700	0.000	403.000	0
Waukesha	L7042GL	1100	l	Clean Burn	c	36	36	0.000	486	170.000	06/17/87	10.200	93.738	267.981	0
Waukesha	L7042GL	1077	l	Clean Burn	c	56	56	0.000	454	0.000	09/17/87	0.000	0.000	245.743	0
Waukesha	L7042GL	1029	l	Clean Burn	c	90	90	0.000	490	0.000	12/17/87	0.000	0.000	277.981	0
Waukesha	L7042GL	941	l	Clean Burn	c	57	57	0.000	456	0.000	03/31/88	0.000	0.000	258.692	0
Waukesha	L7042GL	1081	l	Clean Burn	c	36	36	0.000	537	0.000	07/13/88	0.000	0.000	304.644	0
Waukesha	L7042GL	1100	l	Clean Burn	c	77	77	0.000	533	0.000	02/10/89	9.200	0.000	268.778	0
Waukesha	L7042GL	1100	l	Clean Burn	c	0	39	0.000	440	0.000	09/21/89	10.300	0.000	240.000	2128
Waukesha	L7042GL	1100	l	Clean Burn	c	0	68	0.000	506	202.000	11/15/89	10.000	110.000	271.000	2074
Waukesha	L7042GL	1100	l	Clean Burn	c	0	50	0.000	539	0.000	02/27/90	10.200	0.000	306.000	2109
Waukesha	L7042GU	1108	l	Clean Burn	c	0	42	0.000	534	0.000	05/22/90	10.000	0.000	281.000	2087
Waukesha	L7042GL	1100	l	Clean Burn	c	26	26	0.000	516	184.000	06/17/87	10.100	100.519	281.889	0
Waukesha	L7042GL	1138	l	Clean Burn	c	71	71	0.000	471	0.000	09/17/87	0.000	0.000	254.945	0
Waukesha	L7042GL	929	l	Clean Burn	c	77	77	0.000	446	0.000	12/17/87	0.000	0.000	241.413	0
Waukesha	L7042GL	1007	l	Clean Burn	c	72	72	0.000	464	0.000	03/31/88	0.000	0.000	251.156	0
Waukesha	L7042GL	1048	l	Clean Burn	c	71	71	0.000	478	0.000	07/13/88	0.000	0.000	258.734	0
Waukesha	L7042GL	1100	l	Clean Burn	c	47	47	0.000	448	0.000	09/15/88	0.000	0.000	242.495	0
Waukesha	L7042GL	1100	l	Clean Burn	c	126	126	0.000	603	0.000	02/10/89	8.700	0.000	291.615	0

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MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Waukesha	L7042GL	1100	l	Clean Burn	c	0	37	0.000	484	0.000	09/21/89	10.600	0.000	275.000	2094
Waukesha	L7042GL	1100	l	Clean Burn	c	0	16	0.000	514	0.000	03/02/90	9.800	0.000	268.000	1861
Waukesha	L7042GL	1108	l	Clean Burn	c	0	80	0.000	632	0.000	05/22/90	9.000	0.000	308.000	1734
Waukesha	L7042GL	1108	l	Clean Burn	c	0	34	0.000	528	0.000	08/22/90	10.200	0.000	291.000	1990
Waukesha	L7042GL	1100	l	Clean Burn	c	44	44	0.000	524	176.000	06/17/87	10.200	97.047	288.935	0
Waukesha	L7042GL	1129	l	Clean Burn	c	22	22	0.000	489	0.000	09/17/87	0.000	0.000	269.636	0
Waukesha	L7042GL	937	l	Clean Burn	c	131	131	0.000	572	0.000	01/20/88	0.000	0.000	315.402	0
Waukesha	L7042GL	1012	l	Clean Burn	c	50	50	0.000	465	0.000	03/31/88	0.000	0.000	256.402	0
Waukesha	L7042GL	1051	l	Clean Burn	c	50	50	0.000	535	0.000	07/13/88	0.000	0.000	295.000	0
Waukesha	L7042GL	1100	l	Clean Burn	c	52	52	0.000	604	0.000	09/15/88	0.000	0.000	333.047	0
Waukesha	L7042GL	1100	l	Clean Burn	c	58	58	0.000	541	0.000	02/10/89	9.600	0.000	282.469	0
Waukesha	L7042GL	1100	l	Clean Burn	c	0	46	0.000	496	203.000	09/21/89	9.600	106.000	252.000	1918
Waukesha	L7042GL	1100	l	Clean Burn	c	0	61	0.000	527	0.000	11/15/89	9.800	0.000	288.000	2074
Waukesha	L7042GL	1100	l	Clean Burn	c	0	92	0.000	570	0.000	02/15/90	9.400	0.000	292.000	2010
Waukesha	L7042GL	1108	l	Clean Burn	c	0	38	0.000	559	0.000	05/22/90	9.800	0.000	287.000	2025
Waukesha	L7042GL	1108	l	Clean Burn	c	0	46	0.000	598	179.000	08/22/90	10.200	99.000	330.000	2140
Waukesha	L7042GL	1108	l	Clean Burn	c	0	117	0.000	501	168.000	12/05/91	9.200	85.000	255.000	1922
Waukesha	L7042GL	1100	l	Clean Burn	c	46	46	0.000	513	175.000	06/17/87	10.000	94.725	277.679	0
Waukesha	L7042GL	1108	l	Clean Burn	c	47	47	0.000	487	0.000	09/17/87	0.000	0.000	263.606	0
Waukesha	L7042GL	990	l	Clean Burn	c	47	47	0.000	516	0.000	01/20/88	0.000	0.000	279.303	0
Waukesha	L7042GL	995	l	Clean Burn	c	79	79	0.000	609	0.000	03/31/88	0.000	0.000	329.642	0
Waukesha	L7042GL	1117	l	Clean Burn	c	58	58	0.000	620	0.000	07/13/88	0.000	0.000	335.596	0
Waukesha	L7042GL	1100	l	Clean Burn	c	49	49	0.000	603	0.000	09/15/88	0.000	0.000	326.394	0
Waukesha	L7042GL	1100	l	Clean Burn	c	59	59	0.000	582	0.000	02/10/89	9.500	0.000	301.211	0
Waukesha	L7042GL	1100	l	Clean Burn	c	0	36	0.000	431	206.000	11/15/89	10.100	113.000	233.000	2008
Waukesha	L7042GL	1100	l	Clean Burn	c	0	90	0.000	630	0.000	02/15/90	10.000	0.000	332.000	1933
Waukesha	L7042GL	1108	l	Clean Burn	c	0	29	0.000	623	0.000	08/22/90	10.200	0.000	344.000	2177
Tecogen	CM-75	108	r	Dual Englehards	d	572	99	82.800	*****	27.000	03/30/89	0.100	0.000	0.000	141
Tecogen	CM-60	85	r	Dual Englehards	c	0	10	0.000	0	0.000	09/18/92	0.000	0.000	968.000	0
Caterpillar	G3306	195		Engelhardt NSCC	d	370	35	90.500	*****	26.000	04/21/87	0.001	7.340	3273.102	0
Caterpillar	G398	420	r	HIS Corp	c	152	1	99.300	*****	83.200	03/30/87	0.010	23.498	10116.710	0
Caterpillar	G398	420	r	Houston NSCR	c	606	29	95.215	9679	0.000	12/27/89	0.100	0.000	2732.000	0
Caterpillar	G398	420	r	Houston NSCR	c	603	7	98.800	4067	60.000	09/06/90	0.100	17.000	1148.000	383
Caterpillar	G398	420	r	Houston NSCR	c	0	3	0.000	580	1.000	04/07/92	0.100	1.000	165.000	484
Caterpillar	G398	420	r	Houston NSCR	c	0	2	0.000	4140	1.000	06/10/92	0.100	1.000	2001.000	525
Caterpillar	G398	420	r	HIS Corp	c	402	13	96.800	*****	59.000	03/30/87	0.300	16.898	5914.320	0

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MANUFACTURER	MODEL	HORSE POWER	R/L	CONTROLS	ST	NOX IN	NOX OUT	NOX REDUCED	CO OUT	NMHC PPM	DATE TEST	O2%	NMHC 15%O2	CO 15%O2	QST
Caterpillar	G398	420	r	HIS Corp DN/C	c	331	18	94.600	*****	121.000	04/14/88	0.010	34.174	6764.241	0
Caterpillar	G398	420	r	HIS Corp	c	315	10	96.825	*****	113.000	05/11/89	0.100	32.053	5420.909	0
Caterpillar	G398	420	r	Houston NSCR	c	300	41	86.333	*****	0.000	12/27/89	0.100	0.000	7239.000	0
Caterpillar	G398	420	r	HoustonInd NSCR	c	312	45	85.700	*****	108.000	05/04/90	0.100	31.000	6074.000	495
Caterpillar	G398	420	r	Houston NSCR	c	0	13	0.000	3469	1.000	06/10/92	1.200	1.000	1039.000	554
Caterpillar	G398	420	r	HIS Corp DN/C	c	277	16	94.200	*****	152.000	04/14/88	0.010	42.930	6854.619	0
Caterpillar	G398	420	r	HIS Corp	c	121	11	90.909	*****	190.000	05/11/89	0.100	53.894	10132.400	0
Caterpillar	G398	420	r	HoustonInd NSCR	c	874	21	97.600	3872	42.000	07/26/90	0.100	12.000	1093.000	362
Caterpillar	G398	420	r	Houston NSCR	c	0	33	0.000	8044	1.000	06/10/92	0.100	1.000	2282.000	545
Caterpillar	G398	420	r	Houston NSCR	c	592	11	98.100	6435	29.000	09/06/90	0.100	8.000	1817.000	382
Waukesha	F2895	420	r	Houston NSCR	c	0	5	0.000	5094	1.000	06/10/92	0.300	1.000	1459.000	533
Ingersoll-Rand	SVG-8	440	r	ECS Cat Convert		358	1	99.700	2495	17.000	12/18/87	0.010	4.801	704.667	0
Ingersoll-Rand	SVG-8	440	r	NSCR	m	519	30	94.200	3062	35.600	02/06/89	0.010	0.000	0.000	277
Ingersoll-Rand	SVG-8	440	r	NSCR	m	240	1	99.583	*****	55.000	09/18/89	0.100	15.000	4580.000	343
Enterprise	GSM-8	300	r	LoNOx 43N-10 CC	c	131	2	98.500	*****	103.000	04/22/87	0.200	29.357	11070.050	0
Enterprise	GSM-8	300	r	LONOx Cat Conv	c	33	7	78.800	*****	0.000	06/16/88	0.000	0.000	14265.170	0
Enterprise	GSM-8	300	r	ESC NSCR	c	428	35	91.700	*****	200.000	10/27/89	0.100	57.000	11644.000	115
Enterprise	GSM-8	300	r	ESC NSCR	c	367	1	99.700	*****	182.000	12/11/90	0.010	51.000	3153.000	114
Enterprise	GSM-8	300	r	ESC NSCR	c	0	36	0.000	4929	146.000	05/01/92	0.100	41.000	1398.000	187
Enterprise	GSG-6	520	r	ECS LoNox CC	c	561	3	99.500	6360	30.200	01/14/87	0.100	8.566	1804.038	0
Enterprise	GSG-6	520	r	ESC LoNOx CC	c	728	11	98.489	4992	45.000	12/27/88	0.200	12.826	1422.841	0
Enterprise	GSG-6	520	r	ESC NSCR	c	625	29	95.400	3661	31.000	10/25/89	0.200	9.000	1043.000	364
Enterprise	GSG-6	520	r	ESC NSCR	c	457	22	95.100	7831	65.000	11/20/90	0.200	18.000	2232.000	365
Enterprise	GSG-6	520	r	ECS LoNox CC	c	237	2	99.200	*****	81.400	12/30/86	0.100	23.089	9474.038	0
Enterprise	GSG-6	520	r	ESC LoNOx CC	c	317	16	94.953	*****	110.900	03/28/89	0.500	32.074	4385.667	0
Enterprise	GSG-6	520	r	ESC NSCR	c	325	22	93.200	*****	105.000	10/25/89	0.300	30.000	4822.000	479
Enterprise	GSG-6	520	r	ESC NSCR	c	611	19	96.900	5885	2.000	11/27/90	0.010	1.000	1763.000	500
Enterprise	GSG-6	465	r	LoNOx 43N-10 CC	c	29	2	93.100	*****	153.000	04/15/87	0.100	43.399	11132.850	0
Enterprise	GSG-6	465	r	LONOx Cat Conv	c	39	1	97.400	*****	0.000	06/15/88	0.000	0.000	12839.590	0
Enterprise	GSG-6	465	r	ESC NSCR	c	93	1	98.500	*****	70.000	10/26/89	0.400	20.000	22230.000	884
Enterprise	GSG-6	465	r	ESC NSCR	c	361	5	98.700	*****	22.000	11/21/90	1.000	6.000	3868.000	950
Enterprise	GSG-6	465	r	ESC NSCR	c	0	17	0.000	7727	1.000	03/13/92	0.300	1.000	2213.000	485
Waukesha	VRG220	25		Catalyst		29	1	97.500	*****	248.000	02/23/90	0.100	70.000	3776.000	14
		0				0	15	0.000	7822	55.000	09/09/91	0.100	16.000	2213.000	203
Waukesha	F817GU	190	r	PSC Cat Conv	c	41	41	0.000	484	24.000	12/01/88	5.800	9.377	189.113	0
Waukesha	F817GU	190	r	PSC heat/cogen	c	0	45	0.000	606	38.000	12/13/89	6.500	16.000	247.000	415

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Waukesha	F817GU	190	r	PSC heat/cogen	c	0	37	0.000	567	12.500	01/09/92	5.990	5.000	237.000	183
Waukesha	F817GU	190	r	PSC Cat Conv	c	27	27	0.000	428	132.000	12/10/87	5.500	50.571	163.974	0
Waukesha	F817GU	190	r	PSC Cat Conv	c	30	30	0.000	514	35.000	12/01/88	6.400	14.241	209.145	0
Waukesha	F817GU	190	r	PSC heat/cogen	c	0	39	0.000	583	40.000	12/13/89	6.500	16.000	238.000	415
Waukesha	F817GU	190	r	PSC heat/cogen	c	0	25	0.000	453	10.000	01/09/92	5.700	3.880	175.770	183
Waukesha	145GZU	100	r			53	56	0.000	*****	287.000	05/05/88	0.010	81.058	15816.180	0
Waukesha	145GZU	100	r	PSC PreStrat Ch		24	24	0.000	*****	96.600	10/14/88	15.100	98.266	18774.210	0

TABLE D-3

SANTA BARBARA COUNTY APCD SOURCE TEST DATA

EQUIPMENT	Fuel Type	Rated BHP	Percent Load	Test Load (BHP)	NOx (lbs/hr)	NOx (g/HP-hr)	NOx (ppm)	Control Met
IC Engine, Detroit Diesel, Nodel 671T, Sr. #115341	Oil	213	79	169	2.64	7.09	517	lean-out
IC Engine, Cummins NT855C, Sr. #8109	Oil	335	20	67	0.57	3.87	279	lean-out
IC Engine, Perkins 4236, Sr. #8716	Oil	80	33	27	0.38	6.46	442	lean-out
Cooper-Bessemer I.C. Engine Model GMVA-10, Sr. #46729	Gas	1800	98	1765	1.67	0.43	38	lean-out
Ing-Rand I.C. Engine Model 8SVG, Sr. #8CS1085	Gas	410	105	430	1.43	1.51	107	clean burn
Ingersoll-Rand I.C. Engine Model 8SVG, Sr. #8CS1369	Gas	410	86	352	1.22	1.57	112	clean burn
IC Engine, Detroit Diesel 12V71, Sr. #12V-18207	Oil	456	60	275	5.52	9.11	659	lean-out
I.C. Engine I-R Model LVG-82, Sr. #8AL127	Gas	650	99	646	0.15	0.11	5.64	NSCR
I.C. Engine Ing-Rand Model KVG-62, Sr. #6EL266	Gas	650	90	586	0.16	0.12	13.36	NSCR
I.C. Engine Inger-Rand Lvg-82, Sr. #8AL129	Gas	650	94	610	0.34	0.25	6.51	NSCR
I.C. Engine, Ingersoll-Rand KVG-62, Sr. #6EL265	Gas	660	101	669	0.07	0.05	2.4	NSCR
IC Engine I-R Model LVG-82, Sr. #8AL126	Gas	650	95	619	0.46	0.34	18.22	NSCR
IC Engine Ing-Rand Model KVG-62, Sr. #6EL267	Gas	650	94	613	0.30	0.22	11.87	NSCR
IC Engine Ingersoll-Rand LVG-82, Sr. No. 8AL128	Gas	650	98	640	0.78	0.55	29.78	NSCR
IC Engine (ID #1), Model GMC 471, Sr. #4A271776 (AC Power Gen)	Oil	140	55	77	1.38	8.11	507	lean-out
IC Engine (ID #2), Model GMC 671, Sr. #6A62610RC (AC Power Gen)	Oil	160	41	66	1.35	9.31	594	lean-out
IC Engine (ID #3), Model GMC 671, Sr. #6A46070RC (AC Power Gen)	Oil	160	41	66	0.66	4.55	293	lean-out
IC Engine (ID #4), Model GMC 671, Sr. #6A38930 (AC Power Gen)	Oil	160	55	88	1.79	9.26	578	lean-out
IC Engine M & M #165, #12232, 25 BHP	Gas	25	33	8	0.00	0.00	9.1	lean-out
IC Engine M & M #165, #12233, 25 BHP	Gas	25	33	8	0.01	0.54	20.4	lean-out
IC Engine M & M #165, #12234, 25 BHP	Gas	25	30	8	0.01	0.60	18.6	lean-out
IC Engine M & M #165, #12244, 25 BHP	Gas	25	43	11	0.01	0.42	15.1	lean-out
IC Engine, Waukesha Model 145, #11529, 131 BHP	Gas	131	59	78	0.07	0.41	23.7	lean-out
IC Engine, Waukesha Model 195, #12230, 63 BHP	Gas	63	60	38	0.01	0.12	10.6	lean-out
IC Engine, Waukesha Model 195, #12237, 63 BHP	Gas	63	47	29	0.00	0.00	4.05	lean-out
IC Engine, Waukesha Model 195, #12246, 63 BHP	Gas	63	57	36	0.01	0.13	8.7	lean-out
IC Engine, Waukesha Model 195, #12248, 63 BHP	Gas	63	65	41	0.02	0.22	17.3	lean-out
IC Engine, Waukesha Model 195, #12249, 63 BHP	Gas	63	43	27	0.02	0.33	19	lean-out
M & M HEB # 8066, 46 BHP	Gas	46			?		?	lean-out
IC Engine Caterpillar #G342, #12253, 225 BHP	Gas	225	23	52	0.05	0.44	28.7	lean-out
IC Engine Waukesha 145, #11266, 131 BHP	Gas	131	26	34	0.02	0.27	15.8	lean-out
IC Engine Waukesha 145, #11510, 131 BHP	Gas	131	21	28	0.02	0.32	16.2	lean-out
IC Engine Waukesha 145, #11545, 131 BHP	Gas	131	31	41	0.03	0.33	20.6	lean-out
IC Engine Waukesha 145, #11711, 131 BHP	Gas	131	21	28	0.01	0.16	11.7	lean-out
IC Engine M & M 425, #10966, 39 BHP	Gas	39	29	11	0.01	0.40	15.5	lean-out
IC Engine M & M 425, #11226, 39 BHP	Gas	39	34	13	0.01	0.34	10.4	lean-out
IC Engine M & M 605, #10365, 46 BHP	Gas	46	43	20	0.01	0.23	12.7	lean-out
IC Engine M & M 605, #11279, 46 BHP	Gas	46	57	26	0.02	0.35	18	lean-out
IC Engine M & M 605, #12131, 46 BHP	Gas	46	57	26	0.02	0.35	14.5	lean-out
IC Engine M & M 605, #8505, 46 BHP	Gas	46	45	21	0.01	0.22	12.2	lean-out
IC Engine M & M 605, #9883, 46 BHP	Gas	46	37	17	0.01	0.26	16.5	lean-out
IC Engine Waukesha 145, #9905, 49 BHP	Gas	49	57	28	0.02	0.32	19.7	lean-out
IC Engine Waukesha 145, 11262, 49 BHP	Gas	49	51	25	0.02	0.36	22.0	lean-out
I.C. Engine #1, Norberg FS1381C, Sr. #9018-0577 (AC Power Gen)	Oil	1344	69	925	22.10	10.84	2355	lean-out
I.C. Engine #2, Norberg FS1381C, Sr. #9018-0578 (AC Power Gen)	Oil	1344	79	1063	25.10	10.71	2333	lean-out
I.C. Engine #3, Norberg FS1381C, Sr. #9018-0579 (AC Power Gen)	Oil	1344	75	1013	23.80	10.66	2318	lean-out
I.C. Engine #4, Model Norberg FS1381C, Sr. #9018-0580 (AC Power Gen)	Oil	1344	70	938	22.40	10.84	2345	lean-out

DRAFT

APPENDIX E

ENGINE POWER TEST CODE
SAE J 1349

ARB/SSD December 3, 1997

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(R) ENGINE POWER TEST CODE—SPARK IGNITION AND COMPRESSION IGNITION—NET POWER RATING—SAE J1349 JUN90

SAE Standard

Report of the Engine Committee approved December 1980, completely revised June 1985. Completely revised by the Power Test Code Standards Committee January 1990 and again in June 1990.

Table of Contents

1. *Scope and Field of Application*

1.1 **Scope**—This document has been adopted by SAE to specify:

a. A basis for net engine power rating.

b. Reference inlet air and fuel supply test conditions

c. A method for correcting observed power to reference conditions.
d. A method for determining net full load engine power with a dynamometer.

1.2 **Field of Application**—This test code document is applicable to both four stroke and two stroke spark ignition (SI) and compression ignition (CI) engines, naturally aspirated and pressure charged, with and without charge air cooling. This document does not apply to aircraft or marine engines.

2. *References*

2.1 This test code supersedes those portions of SAE J1349 JUN85 dealing with net power rating.

2.2 Standard CI diesel fuel specifications are range mean values for Type 2-D EPA test fuel per Title 40, Code of Federal Regulations, Part 86.1313-87.

2.3 The corresponding test code for gross power rating is SAE J1995 JAN90.

2.4 The document for mapping engine performance is SAE J1312.

2.5 Relationship to ISO 1585—ISO 1585 (DIS in 1989) differs from SAE J1349 in several areas, among which the most important are:

a. This document is not limited to road vehicles.
b. This document requires inlet fuel temperature be controlled to 40°C on CI engines.
c. This document includes a reference fuel specification and requires that engine power be corrected to that specification on all CI and certain SI engines.
d. This document includes a different procedure for testing engines with a laboratory charge air cooler (ISO method optional).
e. This document stipulates a 20% duty cycle limit on variable speed cooling fans in order to qualify for testing at the minimum power loss settings.

2.6 Complete correlation has not been established with ISO 3046, ISO 2288, ISO 9249, or with ISO 4106. It is expected that these power test codes will eventually align with ISO 1585.

3. *Terms and Definitions*—This section contains the definitions of key terms used to describe the net power test.

3.1 **Net Brake Power**—The power of an engine when configured as a "fully equipped" engine as defined in 3.4 and 5.2, and tested and corrected in accordance with this document.

3.2 **Rated Net Power**—Engine net power as declared by the manufacturer at "rated speed".

3.3 **Rated Speed**—The speed determined by the manufacturer at which the engine power is rated.

3.4 **Fully Equipped Engine**—A "fully equipped" engine is an engine equipped with only those accessories necessary to perform its intended service. A fully equipped engine does not include components that are used to power auxiliary systems. If these components are integral with the engine or for any reason are included on the test engine, the power absorbed may be determined and added to the net brake power. Common "fully equipped" engine accessory examples are listed in Table 4.

3.5 **Reference Test Conditions**—The standard or reference engine inlet air supply (atmospheric) and inlet fuel conditions to which all power corrections are made.

3.6 **Friction Power**—The power required to drive the engine alone as equipped for the power test. Friction power may be established by one of the following methods (the value is needed for power correction of spark ignition engines):

a. Assume 85% mechanical efficiency.
b. Hot Motoring Friction—Record friction torque at wide open throttle at each test speed run on the power test. All readings are to be taken at the same coolant and oil temperature as observed on the power test points ±3°C.

3.7 **Indicated Power**—The power developed in the cylinders. It is defined as the sum of the brake power and friction power for the purpose of this document.

4. *Reference Test Conditions and Corrections*—This section contains reference air and fuel supply test conditions and specifications, recommended test ranges, and applicability of the correction procedures.

4.1 **Reference Atmospheric Conditions**—Table 1 is reference atmospheric conditions and test ranges for which the correction procedures are valid.

TABLE 1—REFERENCE ATMOSPHERIC CONDITIONS

	Standard Condition	Recommended Test Range Limit
Inlet Air Supply Pressure (absolute)	100 kPa	-
Dry Air Pressure (absolute)	99 kPa	90-105 kPa
Inlet Air Supply Temperature	25°C	15-35°C

4.2 **Reference SI Gasoline Specification**—Reference gasoline research and motor octane numbers in Table 2 have been determined corresponding to "regular" and "premium" test fuels. Reference gasoline is required for all SI engines equipped with knock sensors or other devices that control spark advance as a function of spark knock. Other SI engines may use any gasoline with an octane number sufficient to prevent knock.

TABLE 2—REFERENCE SI GASOLINE SPECIFICATIONS

	Regular Fuel	Premium Fuel
Research Octane No.	91 ± 0.5	97 ± 0.5
Motor Octane No.	82 ± 0.5	87 ± 0.5
Lower Heating Value	43.0 MJ/kg ± 0.1	43.1 MJ/kg ± 0.1

4.3 **Reference CI Fuel Specification**—Reference fuel specifications are per Title 40, Code of Federal Regulations, Part 86.1313-87, and represent range mean values for Type 2-D diesel fuel. The reference fuel characteristics in Table 3 have been determined to affect engine test power, and are listed with the applicable test ranges for which the correction procedures are valid.

TABLE 3—REFERENCE CI FUEL SPECIFICATIONS

	Standard Condition	Test Range Limits
Fuel Density at 15°C	0.850 kg/L	0.840–0.860 kg/L
Fuel Kinematic Viscosity at 40°C	2.6 mm²/s	2.0–3.2 mm²/s
Fuel Inlet Temperature	40°C	35-45°C (pump/injectors) or 37-43°C (see in text)

Observed engine power is also corrected for variations in lower heating value (LHV) based on an empirical relationship between LHV and fuel density per 8.4.2.

4.4 **Alternate Fuels**—Reference values for alternate SI and CI fuels, both liquid and gaseous, are not prescribed in this document. Therefore, when alternate fuels are used for the net power engine test, no corrections to reference fuel conditions shall be made.

4.5 **Power Corrections**—The performance of SI and CI engines is affected by the density of the inlet combustion air as well as by the characteristics of the test fuel. Therefore, in order to provide a common basis of comparison, it may be necessary to apply correction factors to the observed net power to account for differences between reference air and fuel conditions and those at which the test data were acquired.

4.5.1 All power correction procedures for atmospheric air are based on the conditions of the engine inlet air supply immediately prior to the entrance into the engine inlet system. This may be ambient (atmospheric) air or a laboratory air plenum that maintains air supply conditions within the range limits defined per 4.1.

4.5.2 On any engine where the power output is automatically controlled to compensate for changes in one or more of the listed inlet air and fuel supply test conditions, no correction for that test parameter shall be made.

4.5.3 The magnitude of the power correction should not exceed 5% for inlet air or 3% for inlet fuel corrections. If the correction factor exceeds these values, it shall be noted in accordance with 7.1.

4.6 **Correction Formulas**—The applicable correction formulas for spark ignition and compression ignition engines are listed in Section 8. These correction formulas are designed for correction of net brake power at full throttle operation; however, for CI engines the formulas may also be used to correct partial load power for the purpose of determining specific fuel consumption. These correction formulas are not intended for altitude derating.

5. *Laboratory and Engine Equipment*—This section contains a list of laboratory and engine equipment used in the net power test.

5.1 Laboratory Equipment—The following standard laboratory test equipment is required for the net power test.

5.1.1 INLET SYSTEM—The intended service inlet system or any laboratory system that provides equivalent restriction at all speeds and loads. The inlet system begins at the point where air enters from the supply source (atmosphere or lab plenum) and ends at the entrance to the throttle body, inlet manifold, or turbocharger inlet, on engines as appropriate.

5.1.2 EXHAUST SYSTEM—A complete intended service exhaust system (including mufflers, catalytic converters, resonators, etc.) or any laboratory system that provides equivalent restriction at all speeds and loads. The exhaust system begins at the exhaust manifold outlet or at the turbine outlet on engines so equipped.

5.1.3 FUEL SUPPLY SYSTEM—Any laboratory system that provides a supply of fuel to the fuel inlet of the fully equipped engine. The fuel supply system must be capable of controlling fuel supply temperature to within the ranges specified in 4.5 for CI engines. The fuel supply system shall not exceed the manufacturer's maximum permissible restric-

TABLE 4—ENGINE EQUIPMENT

System	Required	Comments
1. Inlet Air System	Yes	See 5.1.1.
Air Ducting	Yes	
Air Cleaner	Yes	
Air Preheat	No	
2. Pressure Charging System	Yes	For all engines equipped with variable boost as a function of other engine parameters (speed/load/fuel octane, etc.), the boost pressure controls must be set to reflect intended in-service operation.
Boost Control Settings	Manufacturer's Specification	
3. Charge Air Cooling System	Yes	If applicable.
Charge Air Cooler	Yes	See 5.1.4 for auxillary cooler options.
Cooling Pump or Fan	Conditional	Not required if it can be shown to be functioning less than 20% of running time during intended in-service operation at reference test conditions.
4. Electrical System	Yes	See 5.1.5.
Ignition System	Yes	
Starter	No	
Generator/Alternator	Conditional	Required only if needed to operate the fully equipped engine in a self sustained manner and an external power supply is not used. In this case, the generator shall operate at a load level only sufficient to power the required components (i.e., fuel injectors, electric fuel pump).
Ignition and Timing Control Settings	Manufacturer's Specification	For any engine equipped with electronic controls and/or knock sensors, the spark or timing advance must be adjusted to reflect intended in-service operation.
5. Emissions Control System	Yes	All control settings or adjustments must be set to reflect intended in-service operation.
6. RFI/EMI Controls (radio frequency or electromagnetic	Manufacturer's Specification	Control settings must reflect intended in-service operation.

TABLE 4 (CONTINUED)

System	Required	Comments
7. Fuel Supply System	Yes	
Fuel Filters/Prefilters	Optional	See 5.1.3.
Fuel Supply Pump	Yes	Or equivalent electrical load if applicable.
Injection Pump/Carburetor or Fuel Metering Control Settings	Manufacturer's Specification	Control settings must reflect intended in-service operation.
8. Engine Cooling System (liquid)	Yes	
Cooling Pump	Yes	
Radiator	Optional	Functionally equivalent laboratory system recommended.
Thermostat	Optional	If not used, then coolant temperature and flow shall be regulated to intended in-service levels.
Cooling Fan	Yes	On variable speed units the fan may be run at minimum power consumption levels if it can be shown to be functioning less than 20% of engine running time during intended in-service operation at reference test conditions. NOTE: If for any reason the fan is omitted, the minimum allowable fan power should be determined and subtracted from the net brake power. If run at full output, the fan power absorbed should be calculated and the difference between it and the minimum allowable fan power shall be added to the net brake power.
Engine Cooling System (Air)	Yes	
Blower	Yes	See above comments - same as liquid cooling fan.
9. Lubrication System	Yes	The fully equipped engine closed loop lubrication system is used. Oil fill shall be at manufacturer's full level. Oil temperatures shall reflect in-service levels at reference test conditions.
10. Exhaust System	Yes	See 5.1.2.
11. Auxiliary Drives		
Power Steering Pump	No	
Freon Compressor	No	
Vacuum Pumps	Conditional	Required only if needed to drive other required systems listed, and it functions in that capacity more than 20% of engine running time during intended in-service operation.
Air Compressors	Conditional	See above comments - same as vacuum pumps.

tion requirements, if applicable.

5.1.4 CHARGE AIR COOLER—For charge cooled engines a laboratory auxiliary cooler may be employed for test purposes. If used, one of the following test methods is required and the appropriate correction procedure is applied per Section 9:

a. Standard Method: This is the preferred test method. The laboratory unit is set to simulate intended in-service charge air cooler restriction and inlet manifold temperatures as if the ambient and inlet supply air temperatures were 25 °C.
b. Optional Method: The laboratory unit is set to duplicate the charge air cooler restriction and inlet manifold temperatures that would be obtained during intended service operation at the observed inlet air test conditions.

5.1.5 AUXILIARY POWER SUPPLY—Electrically driven engine components determined to be part of the basic engine may be operated via an external power supply. In such cases, the power required must be determined and subtracted from the corrected net brake power.

5.2 Engine Equipment—A fully equipped engine, as defined in 5.4, is used for the net power test. Table 4 lists fully equipped engine accessories and control settings required for the net power test.

6. ***Test Procedures***—This section contains the required test procedures for determining net engine power.

6.1 Instrumentation Accuracy—The following minimum test instrumentation accuracy is required:

a. Torque: ±0.5% of measured value
b. Speed: ±0.2% of measured value
c. Fuel Flow: ±1% of measured value
d. Temperatures: ±2 °C
e. Air Supply Inlet and Exhaust Pressures: ±0.1 kPa
f. Other Gas Pressures: ±0.5 kPa

6.2 Adjustments and Run-in

6.2.1 Adjustments shall be made before the test in accordance with the manufacturer's instructions. No changes or adjustments shall be made during the test.

6.2.2 The engine shall be run-in according to the manufacturer's recommendation. If no such recommendation is available, the engine shall be run-in until corrected brake power is repeatable within 1% over an 8 h period.

6.3 Pressure and Temperature Measurement

6.3.1 Pressure and temperature of the inlet air supply, used for the purpose of engine power corrections, shall be measured in a manner to obtain the total (stagnation) condition at the entrance to the engine inlet system. On those tests where the engine air supply is ambient air, this pressure is the barometric pressure; on those tests where the air supply is test cell ambient air, this pressure is the cell barometric pressure.

6.3.2 Inlet air pressure, used for the purpose of determining inlet system restriction, shall be measured in a manner to obtain the total (stagnation) pressure immediately prior to the end of the inlet system as defined in 5.1.1.

6.3.3 Inlet manifold pressure and temperature shall be measured as static values with probes located in a section common to several cylinders. In such installations dynamic pressure is assumed zero.

6.3.4 On charge air cooled engines in which a laboratory cooler is employed for testing, precooler charge air pressure must also be measured for the purpose of setting in-service restrictions per 5.1.4. Precooler pressure must be measured upstream of the auxiliary unit in a manner to obtain the total (stagnation) value. Auxiliary cooler restriction is the difference between the precooler and inlet manifold pressures.

6.3.5 Coolant temperatures in liquid cooled engines shall be measured at the inlet and outlet of the engine, in air cooled engines at points specified by the manufacturer.

6.3.6 Oil pressure and temperature shall be measured at the entrance to the main oil gallery.

6.3.7 Fuel temperature shall be measured at the inlet to the carburetor or fuel injector rail for SI engines, and at the inlet to the high pressure injection pump or unit injector rail for CI engines, and at the outlet of the volumetric flow meter for gaseous fueled engines.

6.3.8 Exhaust pressure shall be measured in a manner to obtain the total (stagnation) pressure in a straight section of piping not less than three nor more than six diameters downstream of the entrance to the exhaust system as defined in 5.1.2.

6.4 Test Operating Conditions

6.4.1 The engine must be started and warmed up in accordance with manufacturer's specifications. No data shall be taken until torque and speed have been maintained within 1% and temperatures have been maintained within ±2 °C for at least 1 min.

6.4.2 Engine speed shall not deviate from the nominal speed by more than ±1% or ±10 min⁻¹, whichever is greater.

6.4.3 Coolant outlet temperature for a liquid cooled engine shall be controlled to within ±5 °C of the nominal thermostat value specified by the manufacturer. Coolant inlet air temperature for an air cooled engine is regulated to 25 °C ± 5.

6.4.4 Fuel inlet temperature for diesel fuel injection shall be controlled to 40 °C ± 3 for unit injector systems, and 40 °C ± 1 for pump/line/nozzle systems. Test fuel temperature control is not required on SI engine power tests.

6.4.5 The exhaust gas must be vented to a reservoir having a total pressure within 0.75 kPa of the inlet air supply pressure.

6.5 Test Points—Record full throttle data for at least five approximately evenly spaced operating points to define the power curve between 600 rpm (or the lowest stable speed) and the maximum engine speed recommended by the manufacturer. One of the operating speeds shall be the rated speed, one shall be the peak torque speed.

7. ***Presentation of Results***—This section contains a listing of test data to be recorded and procedures for presenting results.

7.1 Reporting Requirements—All reported engine test data shall carry the notation "Performance obtained and corrected in accordance with SAE J1349". Any deviation from this document, its procedures, or limits shall be noted. All reported or advertised test data bearing the SAE J1349 notation shall include a minimum of the following information at each test point:

a. Engine speed
b. Corrected net brake power (or torque)

7.2 Recorded Test Conditions—Record the following ambient air, fuel, and lubricating oil test conditions and specifications.

7.2.1 INLET AIR SUPPLY CONDITIONS

a. Air supply pressure
b. Air supply vapor pressure
c. Air supply temperature

7.2.2 SPARK IGNITION ENGINE FUEL—LIQUIDS

a. Fuel type and/or blend
b. Research and motor octane numbers
c. Lower heating value

7.2.3 SPARK IGNITION ENGINE FUEL—GASEOUS

a. Fuel type or grade
b. Composition
c. Density at 15 °C and 101 kPa
d. Lower heating value

7.2.4 DIESEL FUELS

a. ASTM or other fuel grade
b. Density at 15 °C
c. Viscosity at 40 °C
d. Lower heating value (optional)

7.2.5 LUBRICATING OIL

a. API engine service classification
b. SAE viscosity grade
c. Manufacturer and brand name

7.3 Recorded Test Data—Record the following minimum information at each data test point:

a. Brake torque
b. Friction torque (if measured)
c. Engine speed
d. Fuel flow rate
e. Fuel supply pressure and temperature
f. Ignition and/or injection timing
g. Oil pressure and temperature
h. Coolant temperature
i. Inlet manifold air temperature and pressure
j. Total pressure drop across the inlet air system
k. Total pressure drop across the auxiliary cooler (if applicable)
l. Total pressure drop across the exhaust system
m. Smoke (optional—CI engines only)

7.4 Engine Equipment—Record all engine equipment listed per 5.2. Additionally, record engine manufacturer, displacement, bore and stroke, number and configuration of cylinders, carburetion or injection system type, plus type of pressure charging system if applicable. If a laboratory charge air cooler is used, record the test method per 5.1.4.

For SI engines equipped with knock sensors, the engine should be designated as a "regular" or "premium" fuel engine. For those SI engines without knock sensors, the minimum octane number for which knock does not occur shall be recorded as stated by the engine manufacturer.

7.5 Additional Recorded Information—Record any other pertinent test data as determined by the manufacturer. This may include, but is not limited to: test date, engine serial number, test number, test location, etc.

8. *Correction Formulas*—This section includes all formulas necessary to correct observed engine power performance for deviations in inlet air and fuel supply conditions.

8.1 Symbols and Units

SYMBOLS	TERM	UNITS
CA	Air correction factor	
CF	Fuel correction factor	
fa	Atmospheric factor	
fm	Engine factor	
fd	Fuel density factor	
fv	Fuel viscosity factor	
α	Pressure sensitivity exponent	
β	Temperature sensitivity exponent	
S	Viscosity sensitivity coefficient	
D	Engine displacement	L
B	Inlet air supply total pressure	kPa
t	Inlet air supply temperature	°C
P	Inlet manifold total pressure	kPa
r	Pressure ratio	
q	Fuel delivery	mg/L cycle
bp	Brake power	kW
fp	Friction power	kW
ip	Indicated power	kW
n	Engine speed	min^{-1}
F	Fuel flow	g/s
SG	Fuel density at 15 °C	kg/L
V	Fuel viscosity at 40 °C	mm^2/s

8.2 Subscripts

- c = Refers to data corrected to reference inlet air and fuel supply conditions.
- o = Refers to data observed at the actual test conditions.
- d = Refers to the dry air portion of the total inlet air supply pressure.
- r = Refers to the reference test conditions per Section 4.

8.3 Spark Ignition Correction Formulas—These spark ignition engine correction formulas are only applicable at full (WOT) throttle positions.

$$bp_r = CA \times bp_o \qquad \text{(Eq.1)}$$

Calculation of atmospheric correction factor, CA. If 85% mechanical efficiency is assumed:

$$CA = 1.18\left[\left(\frac{99}{B_{do}}\right)\left(\frac{t_o + 273}{298}\right)^{.5}\right] - 0.18 \qquad \text{(Eq.2)}$$

If friction power is measured:

$$bp_c = ip_c - fp_o \qquad \text{(Eq.3)}$$

where:

$$ip_c = ip_o\left(\frac{99}{B_{do}}\right)\left(\frac{t + 273}{298}\right)^{.5}$$

and:

$$ip_o = fp_o + bp_o$$

NOTE: If a lab auxiliary charge air cooler is used in conjunction with the standard test method per 5.1.4, no inlet air temperature corrections shall be made. In this case, the temperature correction exponent becomes zero. Otherwise use the above formula.

8.4 Compression Ignition Engine Correction Formulas—These CI engine correction formulas are applicable at all speed and load levels.

$$bp_r = (CA \times CF)\, bp_o \qquad \text{(Eq.4)}$$

8.4.1 CALCULATION OF ATMOSPHERIC CORRECTION FACTOR, CA:

$$CA = (fa)^{fm} \qquad \text{(Eq.5)}$$

where:

$$fa = \left(\frac{B_{dr}}{B_{do}}\right)^{\alpha}\left(\frac{t_o + 273}{t_r + 273}\right)^{\beta} = \left(\frac{99}{B_{do}}\right)^{\alpha}\left(\frac{t_o + 273}{298}\right)$$

and values for α and β, are summarized in Table 5:

TABLE 5—ATMOSPHERIC CORRECTION FACTOR EXPONENTS

Pressure Charging System	Charge Air Cooling System	α	β
Naturally Aspirated	None	1.0	0.7
Mechanically Supercharged	All	1.0	0.7
Turbocharged	None	0.7	1.2
Turbocharged	Air-to-Air	0.7	1.2
Turbocharged	Jacket Water	0.7	0.7
Turbocharged	Lab Auxiliary (Standard)	0.7	0.4
Turbocharged	Lab Auxiliary (Optional)	0.7	1.2

Where "standard" and "optional", refer to the lab auxiliary cooler test method described in 5.1.4.

The value of fm is given as:

q/r	fm	
Less than 37.2	0.2	(Eq.6)
Between 37.2 and 65	$(0.036 \times q/r) - 1.14$	
More than 65	1.2	

where:

q = 120 000 F/Dn for four stroke engines
q = 60 000 F/Dn for two stroke engines
r = P_o/B_o for all engines (r = 1 if naturally aspirated)

8.4.2 CALCULATION OF FUEL CORRECTION FACTOR, CF:

$$CF = fd \times fv$$

where:

$$fd = 1 + 0.70\left(\frac{SG_r - SG_o}{SG_o}\right) = 1 + 0.70\left(\frac{0.850 - SG_o}{SG_o}\right) \qquad \text{(Eq.7)}$$

and:

$$fv = \frac{1 + S/V_o}{1 + S/V_r} = \frac{1 + S/V_o}{1 + S/2.6}$$

NOTE: The above formulas correct observed power to reference fuel density and viscosity levels. A correction coefficient of 0.70 in the above density factor equation is added to account for typical changes in lower heating value at differing density levels, based on an empirical LHV-SG relationship.

Values of S shall be determined by the engine manufacturer. If no values are available, the following shall be used:

a. Pump/Line/Nozzle Systems 0.15
b. Unit Injectors 0.3

NOTE: If used for the purpose of determining specific fuel consumption, the corrected fuel flow is given by the following:

$$F_c = (SG_r/SG_o \times fv)\, F_o \qquad \text{(Eq.8)}$$